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Final

**Monterey Pine Forest Ecological Assessment:
Historical Distribution, Ecology, and
Current Status of Monterey Pine**

Submitted by:

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Submitted to:

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California Department of Fish and Game
Natural Heritage Division
1416 Ninth Street
Sacramento, CA 95814-2090

Funded by:

Emergency Drought Relief Project
Contract No. CA HER 082493

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INTRODUCTION

Monterey pine (*Pinus radiata*) is restricted to five locations, three in coastal California and two on islands off the coast of Baja California (Figures 1 and 2). Though Monterey pine is of limited distribution in its native habitat and is of little economic importance in the United States, it is the most widely planted pine tree in the world and of great economic importance in other countries (Critchfield and Little 1966, Roy 1966).

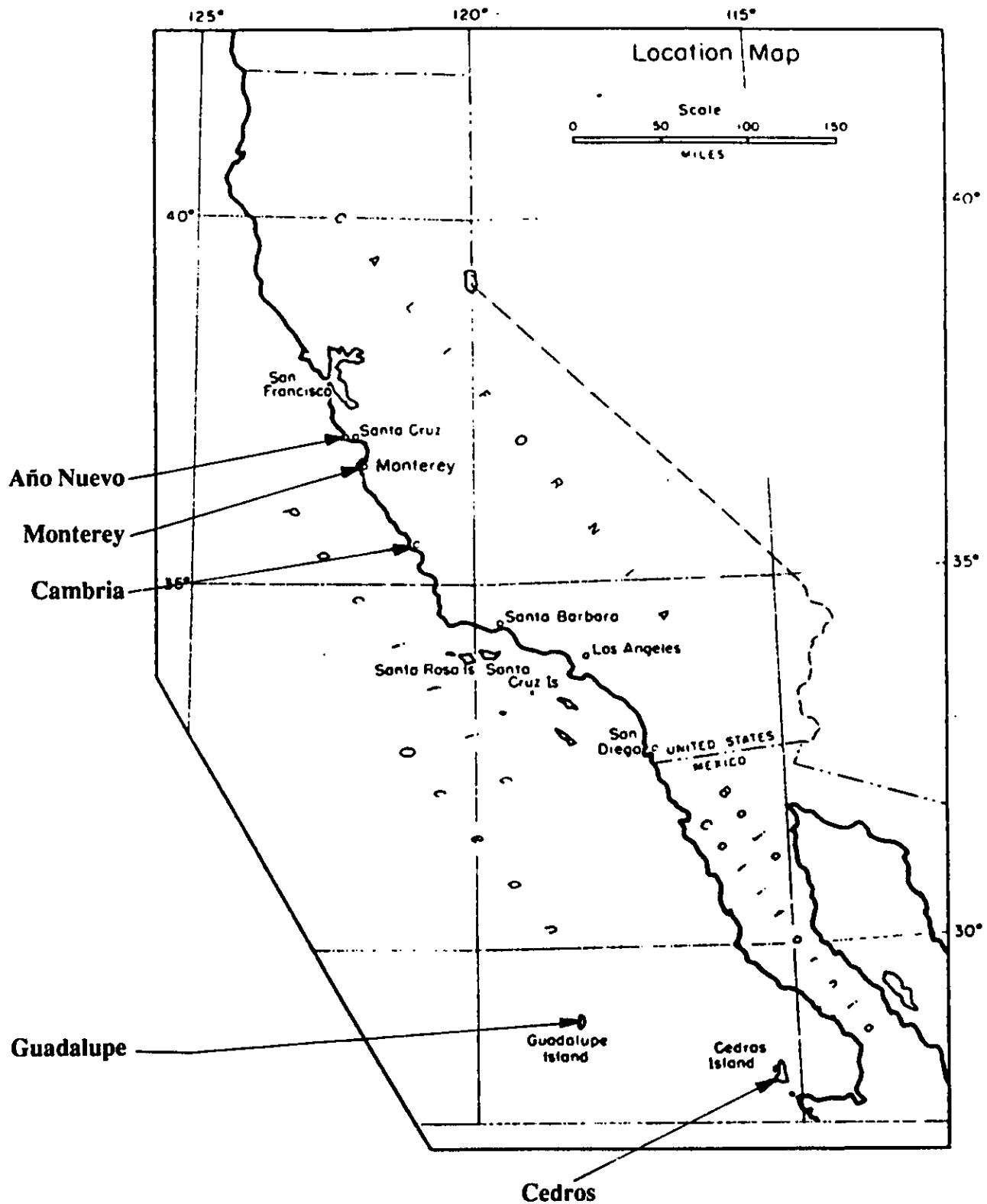
The purpose of this report is to provide a compilation of information on the distribution, ecology, and current status of Monterey pine. The need for a study of Monterey pine stemmed from the realization that much of the Monterey pine forest had been and continues to be removed for development and that much of the remaining forest has become fragmented by this development. The California Department of Fish and Game (DFG) and The Nature Conservancy (TNC) have sponsored this study in an effort to gain a better understanding of:

- Monterey pine as a species,
- Monterey pine forest as a biological community,
- the extent and character of the contemporary Monterey pine forest,
- the extent and character of historical Monterey pine forest, and
- the nature and extent of alterations to the native Monterey pine forest.

These data will be used in the development of a conservation plan for Monterey pine and Monterey pine forest. Two other reports on Monterey pine ecology have been prepared by Jones & Stokes Associates for DFG and TNC. New findings concerning the relationships between Monterey pine forest and geomorphic features are described in the report *The Monterey Ecological Staircase: the Nature of Vegetation and Soils of Different Geomorphic Surfaces of the Monterey Peninsula with an Emphasis on Monterey Pine* (Jones & Stokes Associates 1994a). A list of published and unpublished references on the ecology of Monterey pine is provided in the report *Selected Bibliography on Monterey Pine (Pinus radiata D. Don)* (Jones & Stokes Associates 1994b).

The description of Monterey pine ecology in this report is subdivided into ecological subdisciplines and information is presented in the following sections:

- Species description
- Distribution
- Reproductive biology
- Growth
- Systematics/Taxonomic relationships
- Associated species
- Soils and roots
- Fire ecology and ecological succession
- Diseases and pests
- Commercial uses



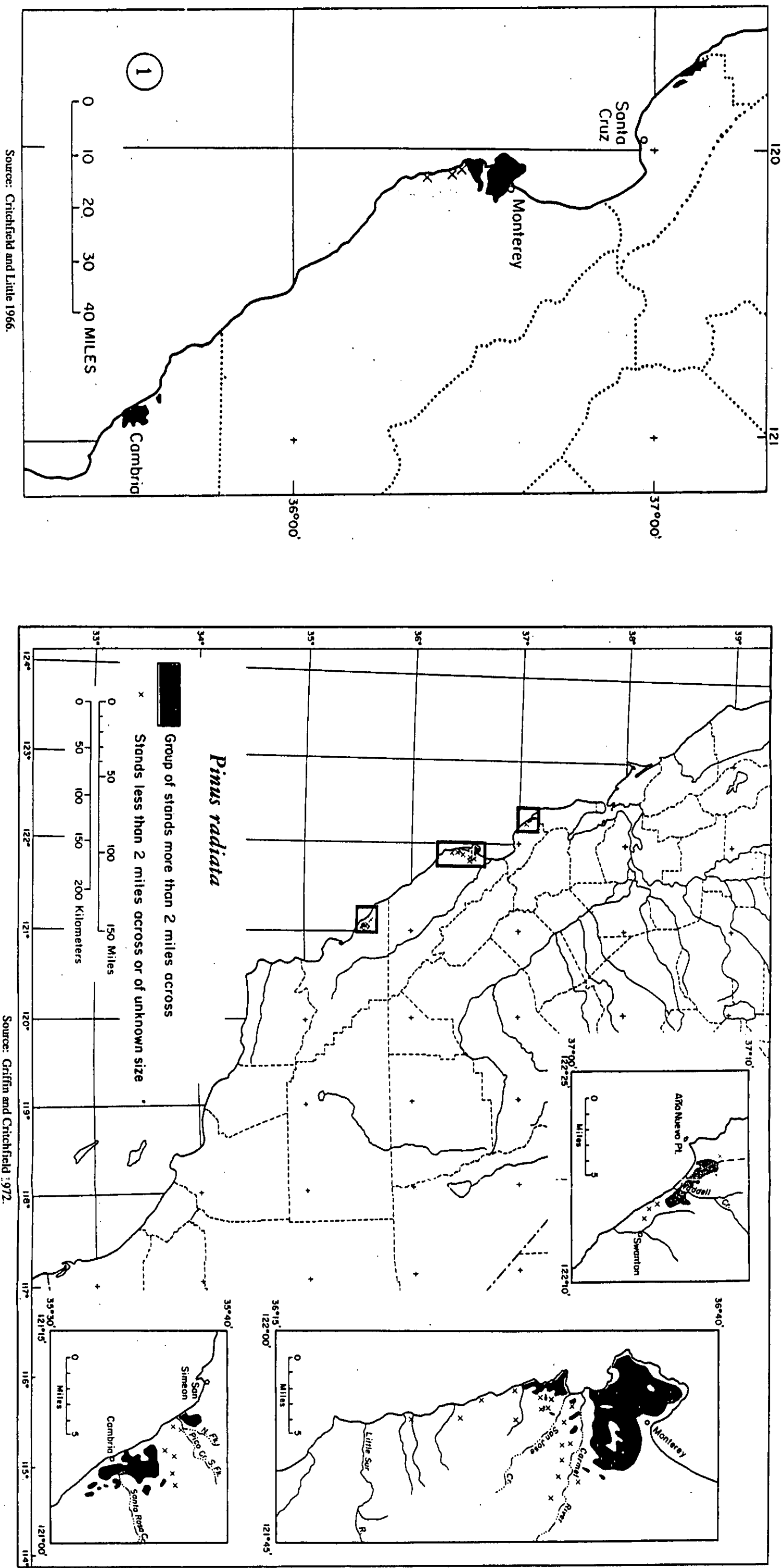
Source: Modified from Roy 1966.



Jones & Stokes Associates, Inc.

Figure 1
Locations of Indigenous Populations
of Monterey Pine

Figure 2
Distribution of Monterey Pine Forest
in California as Mapped in
Various Reports



- Stand health
- Genetic effects of nursery stock
- Land use

METHODS

Literature Review and Personal Communications

Most of the information on Monterey pine presented in this report was obtained through a review of published and unpublished literature and personal communications with individuals knowledgeable about Monterey pine. Key summary articles on Monterey pine cited extensively in this report are Coleman 1905, Scott 1960, Roy 1966, and McDonald and Lacke 1990.

Historical and Present Distribution

Historical and present distribution of Monterey pine forest was determined using several methods. Historical and present distributions of Monterey pine and Monterey pine forest were obtained from various published reports. In addition, Jones & Stokes Associates conducted original mapping of existing Monterey pine forest. To estimate the historic extent of Monterey pine forest at Monterey, we combined our original data on the relationship between geomorphic surfaces and vegetation from Jones & Stokes Associates (1994a), an existing map of geomorphic surfaces by Dupre (1990), and our map of the present distribution.

Jones & Stokes Associates mapped present Monterey pine forest cover and all other land cover types within and surrounding the Monterey pine forest in the Monterey area. The land cover classification system used consisted of the following mapping units:

- Monterey pine forest
- Cypress forest
- Pygmy forest
- Bishop pine forest
- Other forest types (e.g., redwood forest and Douglas fir forest)
- Oak woodland and savanna
- Riparian forest and scrub
- Chaparral and coastal scrub
- Chaparral/grassland mosaic
- Grassland
- Agricultural land
- Developed land

Monterey pine forest was further divided into the following forest subtypes:

- Monterey pine forest
- Monterey pine-bishop pine mixed forest
- Monterey pine riparian forest

Mapping was conducted on 1:12,000 scale acetate topographic base maps (enlarged from 1:24,000 scale U.S. Geological Survey quadrangles) overlain on false-color infrared aerial photographs at the same scale. Land covers were identified from the aerial photographs and rectified to the topographic overlay map using identifiable common features such as streams, ridgecrests, and roads. The minimum mapping unit was approximately 5 acres. All map units contain smaller areas of other cover types that were subsumed into larger mapping units.

Field surveys were conducted on February 15-16, March 24-27, and April 12, 1994, to ground verify aerial photograph "signatures" of vegetation mapping units, gather additional ecological data, and confirm the eastward extent of Monterey pine distribution. However, most of the effort during these field surveys was expended in gathering site data on the association between Monterey pine forest, soils, and geomorphic surfaces. See Jones & Stokes Associates (1994a) for a description of this work.

Commercial Use

Information on commercial use of Monterey pine and the genetic changes resulting from commercial forest improvement programs was obtained from published reports and contacts with knowledgeable individuals.

Species Associations

Species associations information for Monterey pine forest was obtained through literature reviews and original field work conducted by Jones & Stokes Associates. General Monterey pine forest species associations are discussed in this report. A classification system for Monterey pine forest subtypes was developed based on vegetative composition, geomorphic surfaces, and soils. See Jones & Stokes Associates (1994a) for a description of the methods, results, and conclusions of this classification system.

Stand Composition and Health

Most information on stand composition and health of Monterey pine forest was obtained from Huffman and Associates (1994). Jones & Stokes Associates conducted a

survey of forest conditions and land uses on the Monterey Peninsula. The survey was conducted on February 16, 1994, and used roadside reconnaissance and contacts with knowledgeable individuals to obtain site information. The results of this survey are presented in Appendix A.

Fire History

Sources used to obtain information on the fire history of the Monterey Peninsula were the City of Monterey Fire Departments (Reid and Rodewald pers. comms.) and the California Department of Forestry and Fire Protection's fire analysis of the Morse fire (Taylor 1987), fire history maps on file at the King City office, and knowledgeable staff (Marlow, Washington, and Musgrove pers. comms.). Jones & Stokes Associates contacted the Sacramento office of the California Department of Forestry and Fire Protection (CDF) to request fire history information for the Monterey Peninsula (Spiro pers. comm.). The CDF database is incomplete and only contains records of fire occurrences since 1980. This database consists of points at the center of topographic map sections indicating where incidents have occurred and includes information on cause, date, and acreage of fire. CDF typically only has information on fires on lands for which the state is responsible. This task proved to be difficult because of the lack of data, historical records, and mapped locations of burn limits.

Genetic Effects of Nursery Stock

The genetic effects of nursery stock on native stands of Monterey pine were assessed based on published literature and contacts with knowledgeable individuals.

Land Uses

Jones & Stokes Associates mapped land uses within areas that support Monterey pine. Mapping was conducted simultaneously and the methods were the same as those described above in the section "Historical and Present Distribution" using aerial photograph interpretation, acetate topographic overlays, and some ground verification. The minimum mapping unit was approximately 5 acres. The following land use mapping units were delineated on the topographic base mylar:

- **Urban.** These areas are heavily developed with sparse occurrences of Monterey pine, mostly as street trees and never forming a forest. Many other species of horticultural trees occur here. Examples include the downtown areas of Monterey, Pacific Grove, and Carmel.

- **Urban, golf course, urban park.** These areas support mostly development, but scattered Monterey pine are present, sometimes with up to 20% canopy cover. Many other species of horticultural trees occur here. Examples include the urban neighborhoods of Monterey, Pacific Grove, and Carmel.
- **Suburban.** These areas support a Monterey pine canopy, usually over 20% cover, with structures and yards underneath. Vegetation in the understory is usually non-native landscaping. It is uncertain where the Monterey pine forest is planted or naturally established within these areas. Examples include suburban areas of Pebble Beach, Pacific Grove, Monterey, and Carmel Highlands.
- **Rural.** These areas support Monterey pine forest with rural development underneath. Lot sizes are greater than 1 acre. Much of the understory may be natural vegetation except around structures and roads. In some areas the understory may be cleared or highly managed. Examples include the larger lot development areas of Pebble Beach, Monterey, and inland areas.
- **Undeveloped.** These areas support Monterey pine forest with naturally established, relatively undisturbed understory. Structures and roads may be present, but do not substantially break up the forest cover. Examples include undeveloped areas of Pebble Beach, inland areas around Jack's Peak, Point Lobos State Park, and Lobos Ranch.

Geographic Information System Data Entry

Land cover and land use data collected by Jones & Stokes Associates were entered into a geographic information system (GIS). Geology data for the Monterey Peninsula from Dupré (1990) were entered into the GIS by Jones & Stokes Associates with modifications based on Jones & Stokes Associates' field survey data. In addition, soil survey data for the Monterey Peninsula were obtained in GIS format from U.S. Soil Conservation Service. GIS coverages for the Monterey Peninsula created or obtained by Jones & Stokes Associates are:

- Land cover types (including Monterey pine occurrences subdivided by land use)
- Geologic surfaces
- Soils

Comparison of Ecological Conditions and Land Uses

A comparison of ecological conditions and land uses was conducted using GIS data layers. Land cover acreages were calculated using GIS.

SPECIES DESCRIPTION

In 1830 at Monterey, Thomas Coulter became the first botanist to collect specimens of Monterey pine (Griffin and Critchfield 1972). The species was first classified and named by the Scottish botanist David Don (Stoddard 1947).

Monterey pine is a tall, straight-trunked tree. Mature trees are typically 60-90 feet tall (Sudworth 1967). Needles are typically in clusters (fascicles) of three and are 2.5 to 6 inches long (Hickman 1993). On some trees, two- and three-needed fascicles are present and on the varieties of Monterey pine from Mexico nearly all fascicles are two needed. Branches and cones form whorls (actually tight spirals) about stems. Seed cones are conically shaped but asymmetrical and up to 6 inches long. The cones remain closed and persist on the tree for many years. Young trees have narrow, rounded crowns and older trees have flat crowns (Sudworth 1967). Monterey pine exposed to wind and salt spray are usually of low stature, are wind-pruned, and have twisted trunks and branches.

DISTRIBUTION

Miocene, Pliocene, and Pleistocene Epochs

Fossil evidence of Monterey pine in California from the late Miocene Epoch through the Pleistocene Epoch, a period between about 7 million to 10,000 years ago, has been found in coastal areas from Tomales Bay to Rancho La Brea (Axelrod 1967, 1980, 1988; Cain 1944). The closed-cone pine species, including Monterey pine, formed a continuous forest on the outer coast and islands as recently as the late Pleistocene Epoch (14,500-12,000 years ago) (Axelrod 1967). The distributions of Monterey pine, Bishop pine (*Pinus muricata*), and knobcone pine (*Pinus attenuata*) overlapped to a much greater extent at that time than they do today (Langenheim and Durham 1963, Axelrod 1967). As the climate became hotter and drier, Monterey pine became more restricted to the immediate coast (Axelrod 1967). Populations of Monterey pine became isolated from each other at favorable climatic sites along the coast.

Holocene Epoch

During the Holocene Epoch, starting about 10,000 years ago, Monterey pine forests became restricted to five locations, three in California and two on islands off the coast of Baja California (Figures 1 and 2) (Roy 1966, Griffin and Critchfield 1972). The northernmost forest is between Año Nuevo and Swanton (referred to hereafter as the "Año Nuevo" occurrence) in southern San Mateo and northern Santa Cruz Counties (Figures 2 and 3). The largest area of Monterey forest occurs in northern Monterey County on the

Monterey Peninsula, inland areas from the peninsula, and Point Lobos (referred to hereafter as the "Monterey" occurrence) (Figures 2, 4, and 5). Monterey pine forest occurs in San Luis Obispo County from north of Pico Creek to south of Cambria (referred to hereafter as the "Cambria" occurrence) (Figures 2 and 6).

Two smaller occurrences of Monterey pine are on Guadalupe and Cedros Islands, Mexico (Libby et al. 1968) (Figures 1 and 7). These pines have needles in groups of two, rather than three, and are called Guadalupe Island pine (*Pinus radiata* var. *binata*) and Cedros Island pine (*Pinus radiata* var. *cedrocensis*). Cedros Island supports the southernmost population and is relatively close to the mainland (referred to hereafter as the "Cedros" occurrence). Guadalupe island supports Monterey pine forest on its northern end (referred to hereafter as the "Guadalupe" occurrence). Guadalupe Island is about 175 miles from mainland Baja California.

Present

Indigenous Forest

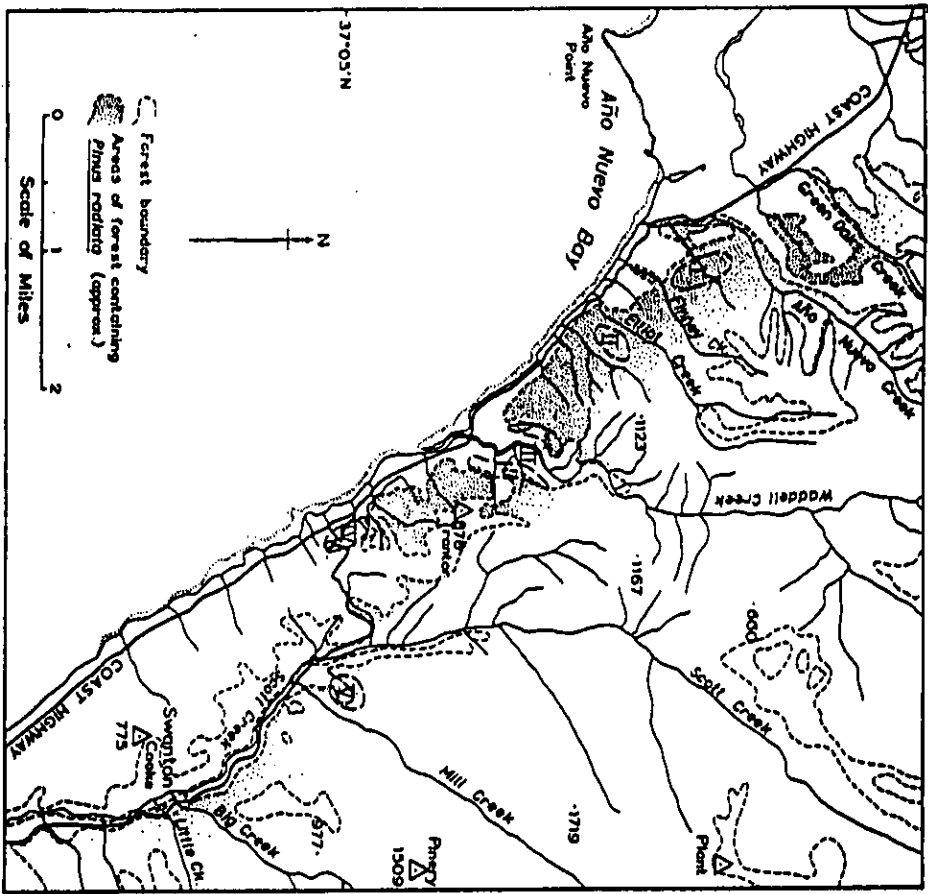
Scott (1960) states that the extent of Monterey pine forest in 1931 was 6,000 acres at Monterey, 2,000-3,000 acres at Cambria, and a few hundred acres at Año Nuevo. Roy (1966) estimated the size of the Monterey pine forest to be between 8,000-12,000 acres at Monterey; about 3,000 acres at Cambria; and less than 1,000 acres at Año Nuevo with much of the pine in mixed stands (Figures 3, 5, and 6). McDonald (1959) estimated the total area of four occurrences of Monterey pine forest (he did not include the Cedros occurrence) to be about 30,000 acres, with the Monterey occurrence comprising approximately 12,000 acres of the total (Figure 4).

A recent report on remaining natural forests of Monterey pine estimates that Monterey supports 6,900 acres of "native stands," Cambria supports 2,300 acres, and Año Nuevo supports 1,500 acres (Figures 3, 6, and 8) (Huffman and Associates 1994). Estimates from Jones & Stokes Associates' forest mapping indicates that about 9,400 acres of Monterey pine with natural understory occurs at Monterey (Figure 9).

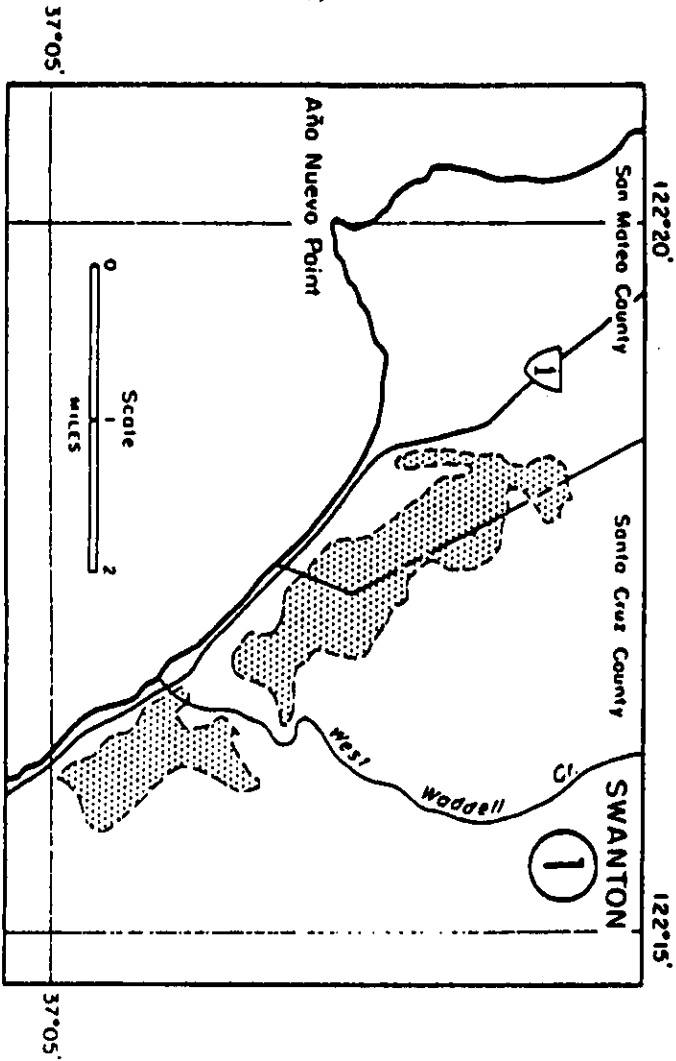
Significant differences exist between the extent of remaining "natural" Monterey pine forest at Monterey estimated by Jones & Stokes Associates and that estimated by Huffman and Associates (1994). Huffman and Associates (1994) identified 6,900 acres of remaining Monterey pine forest in native stands (Figure 8). Jones & Stokes Associates identified 9,405 acres of remaining Monterey pine forest in undeveloped areas with natural understory vegetation (Figure 9). There appear to be four main reasons for these differences:

1. Different forest cover type criteria were used. Jones & Stokes Associates mapped Monterey pine forest with natural understory. Huffman and Associates (1994) mapped "native stands" of Monterey pine forest, a classification not clearly defined in the report. Many of the sites mapped in the two efforts

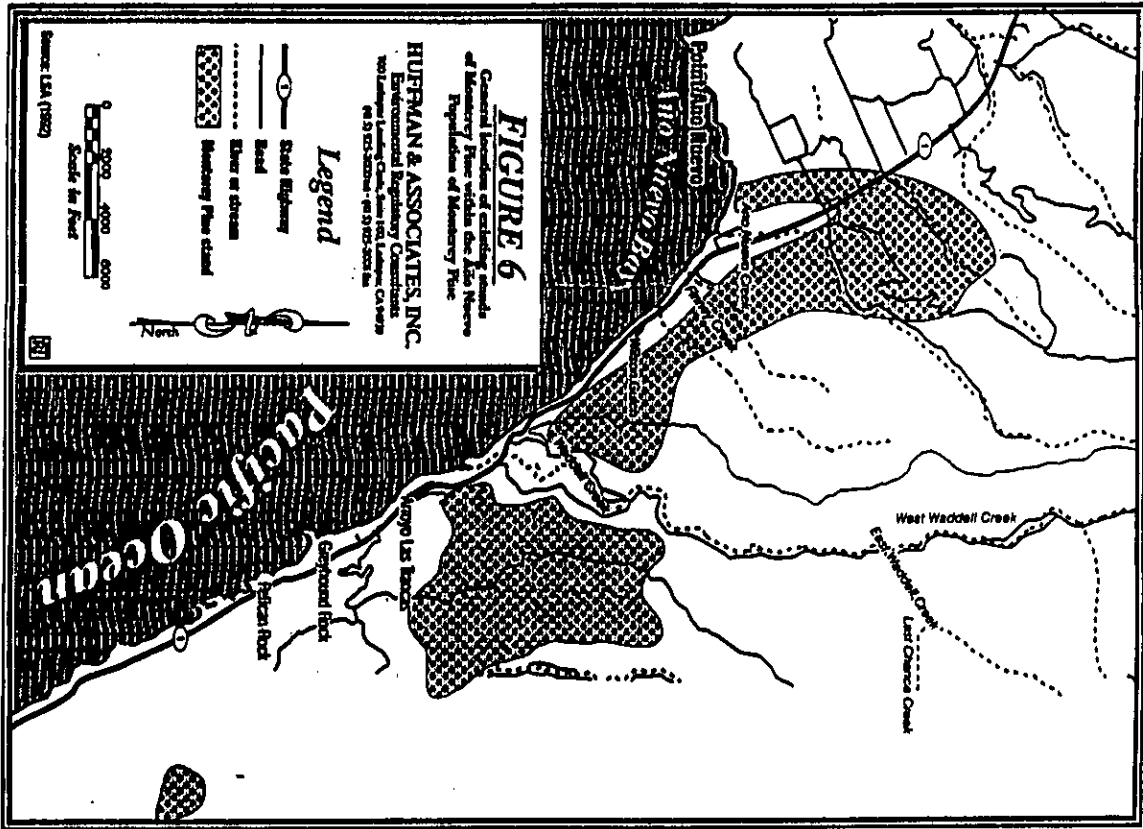
Figure 3
Distribution of Monterey Pine Forest
at Año Nuevo as Mapped In
Various Reports



Areas Containing Monterey Pine Forest at Año Nuevo
Source: Forde 1964.



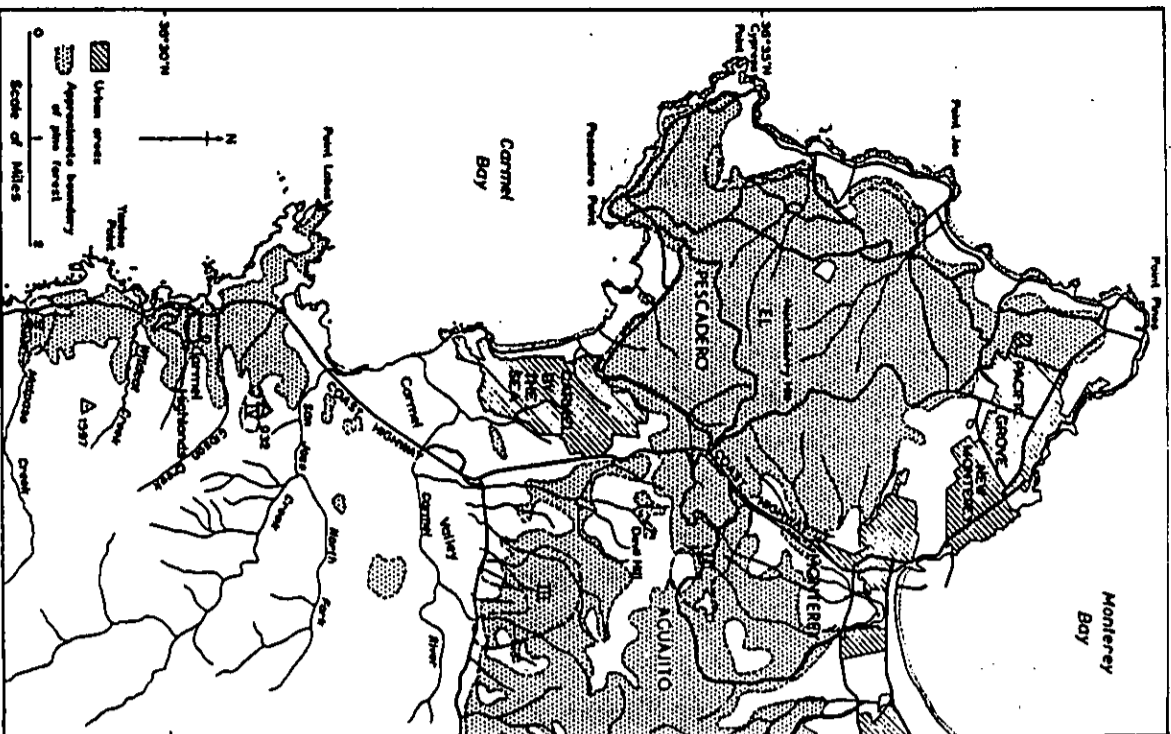
Natural Range of Monterey Pine at Año Nuevo
Source: Roy 1966.



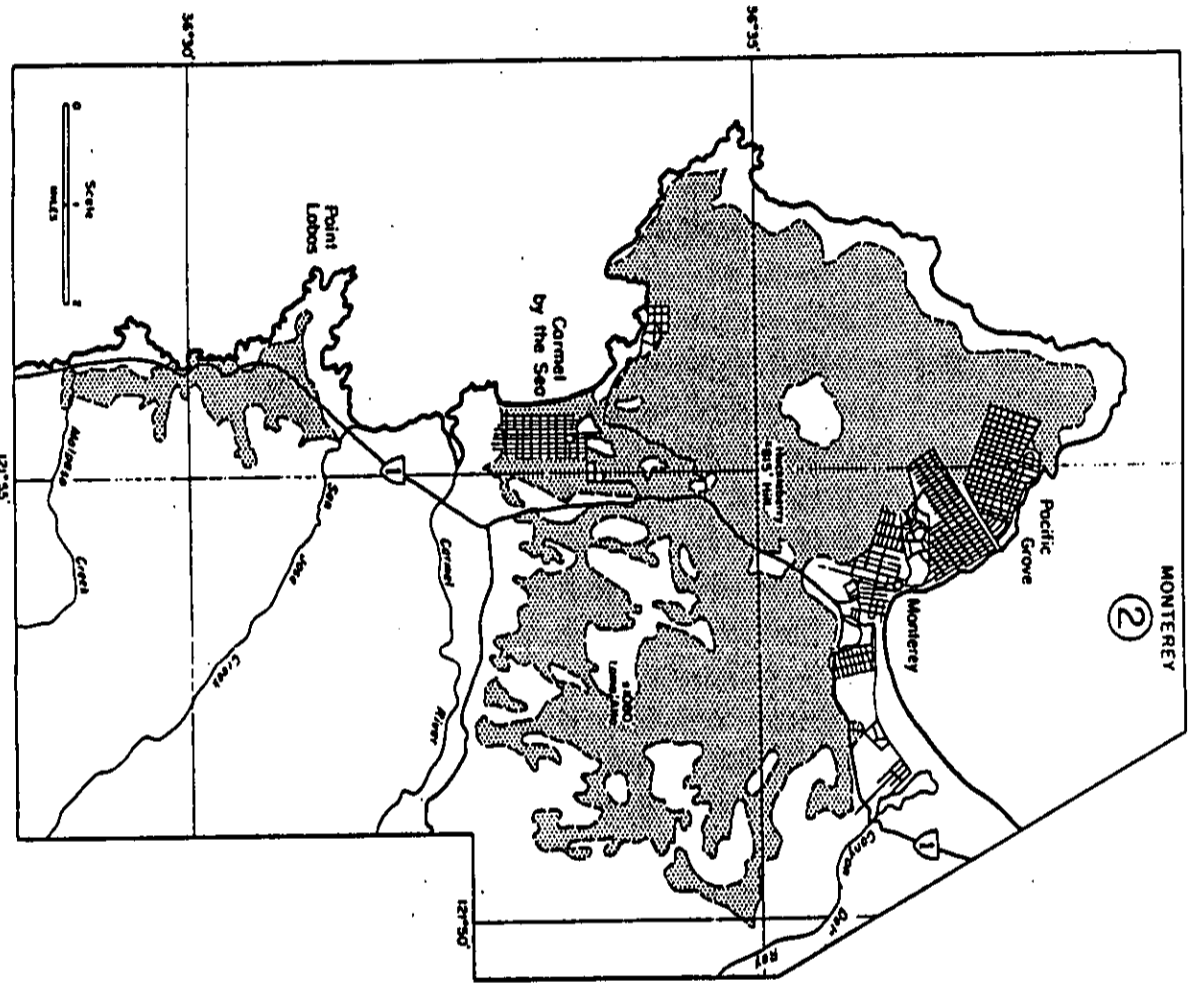
Present Distribution of Monterey Pine Forest at Año Nuevo
Source: Huffman and Associates 1994.



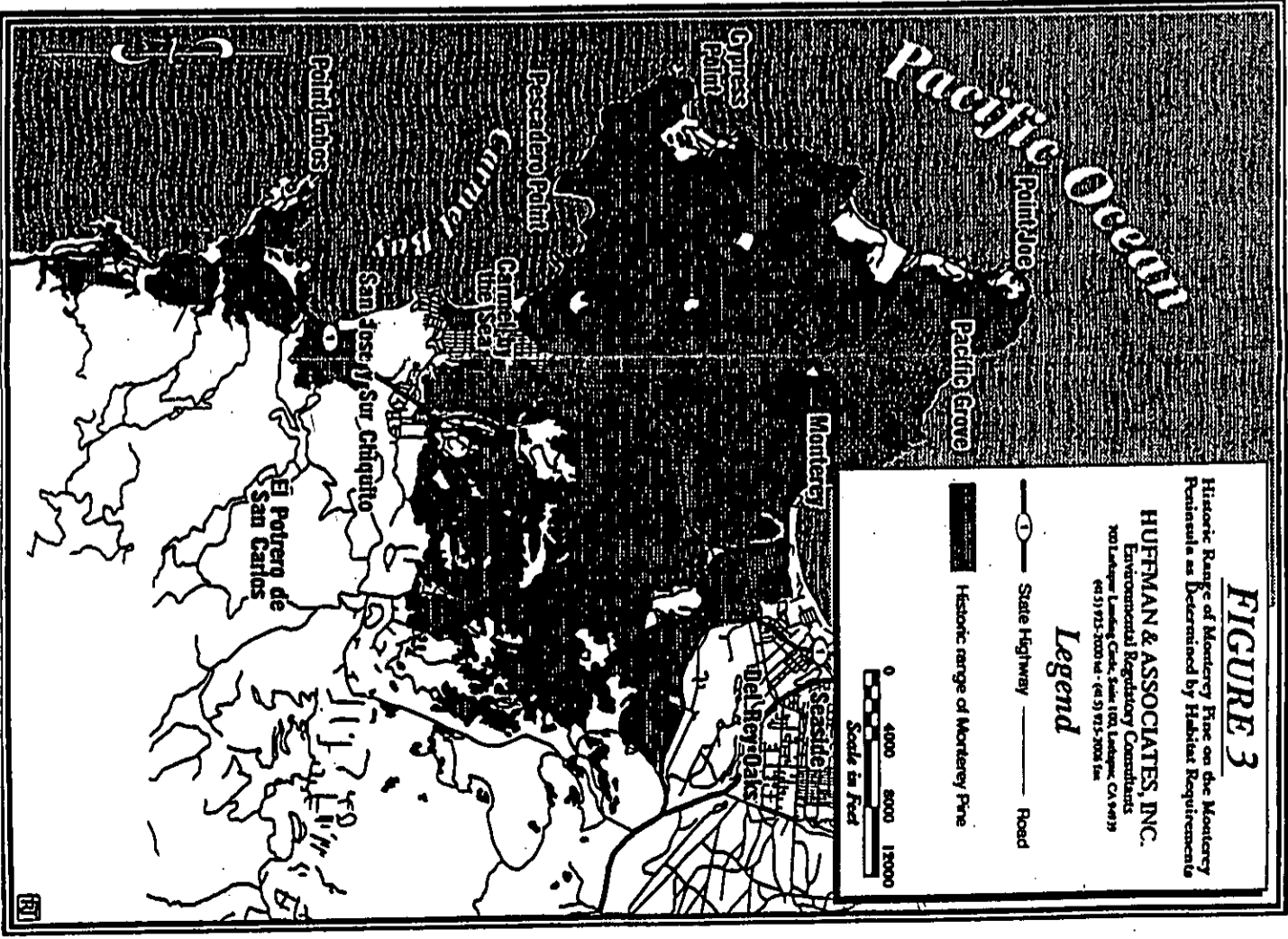
Figure 5
Various Approximations of the Natural
Distribution of Monterey Pine Forest
at Monterey



Approximate Boundary of Monterey Pine Forest at Monterey
Source: Forde 1964.



Natural Range of Monterey Pine at Monterey
Source: Roy 1966.

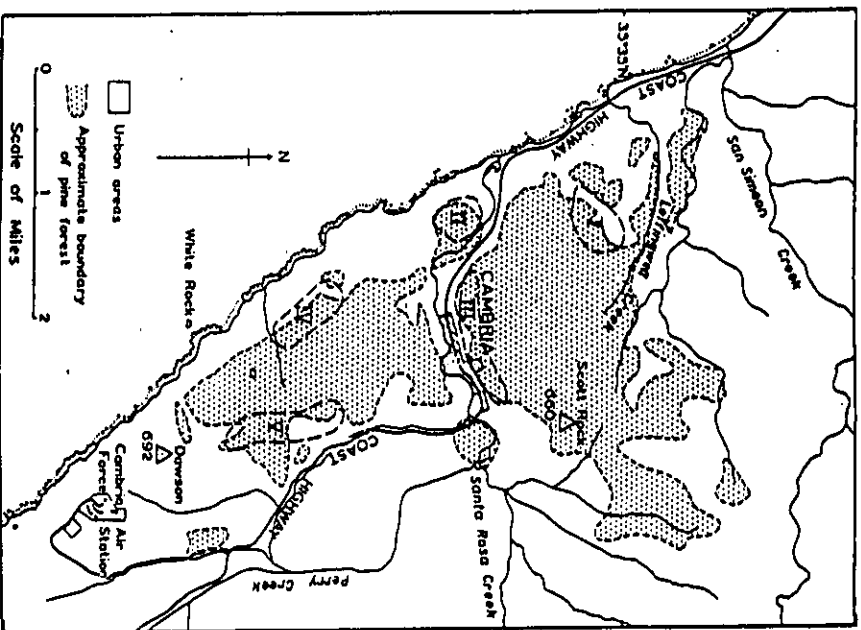


Historical Range of Monterey Pine Forest at Monterey
Approximated by Huffman and Associates
Source: Huffman and Associates 1994.

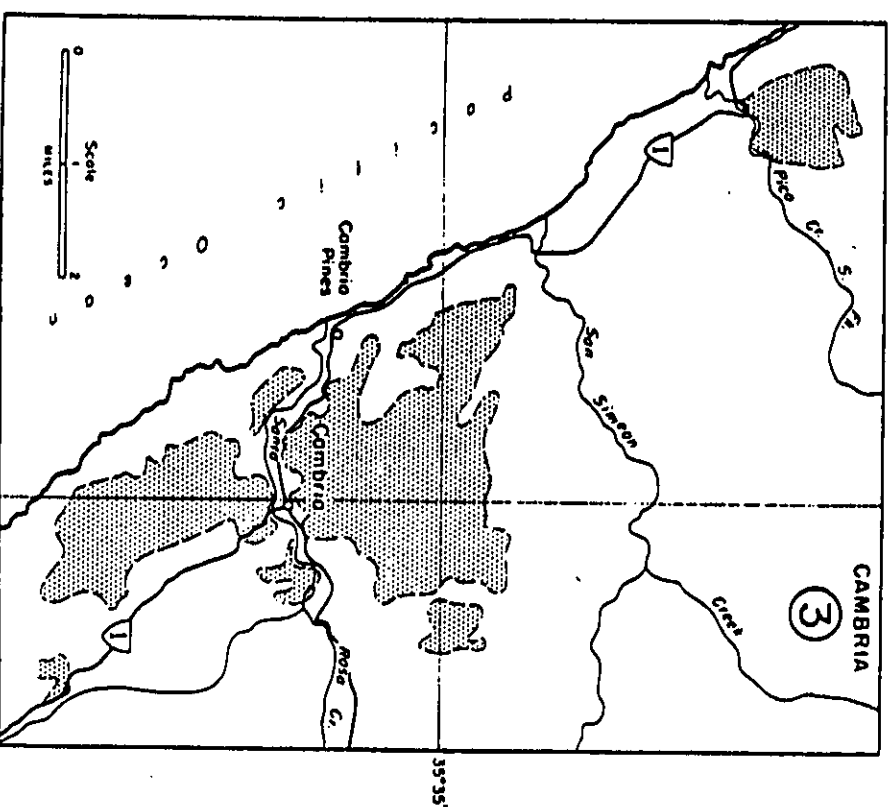


Jones & Stokes Associates, Inc.

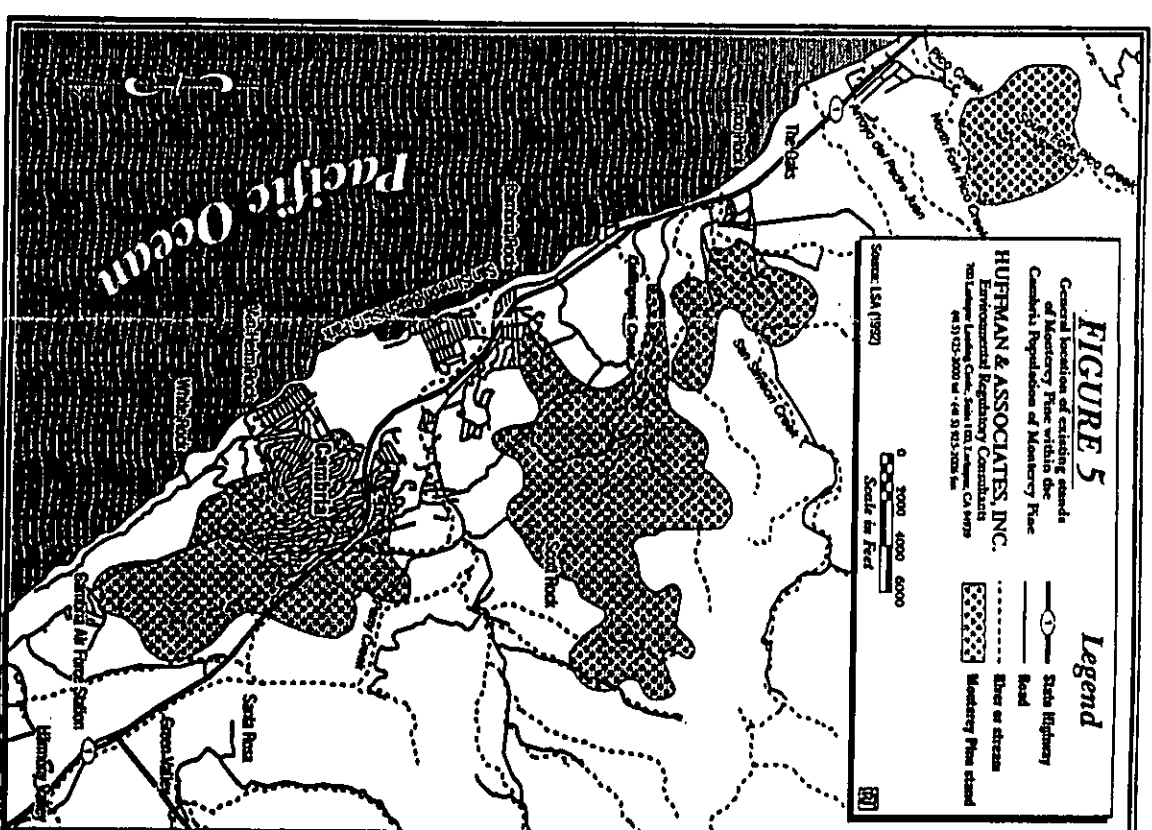
Figure 6
Distribution of Monterey Pine Forest
at Cambria as Mapped In
Various Reports



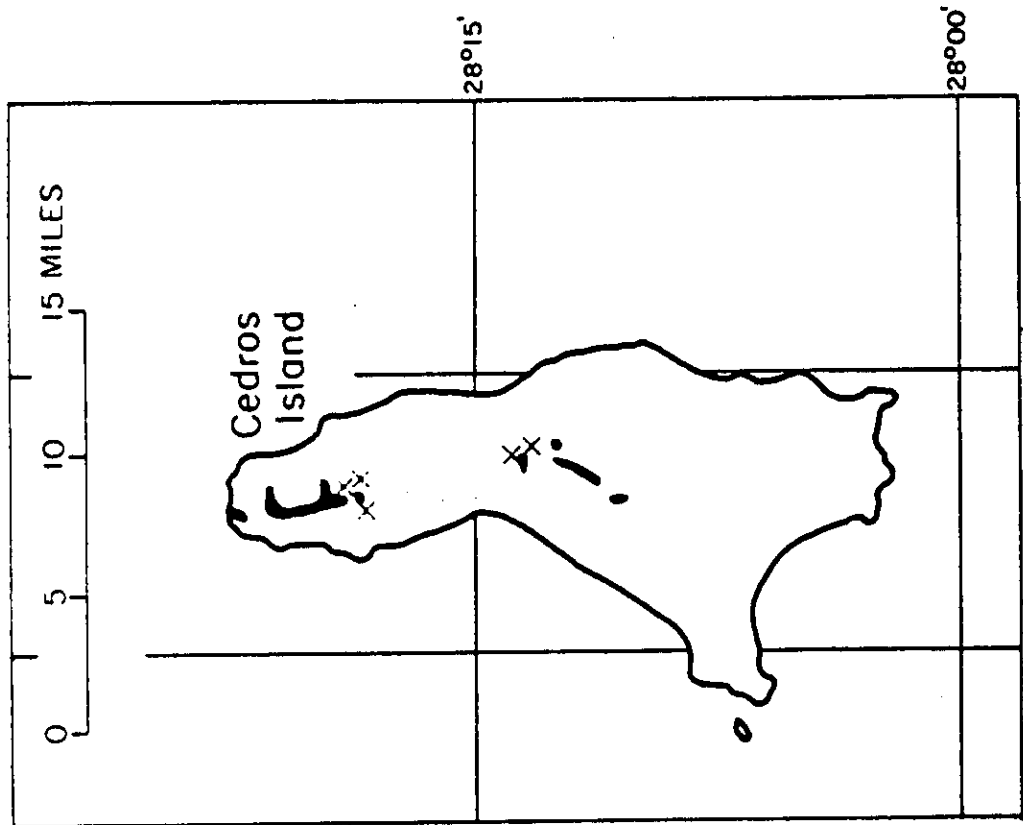
Approximate Boundary of Monterey Pine Forest at Cambria
Source: Forde 1964.



Natural Range of Monterey Pine at Cambria
Source: Roy 1966.

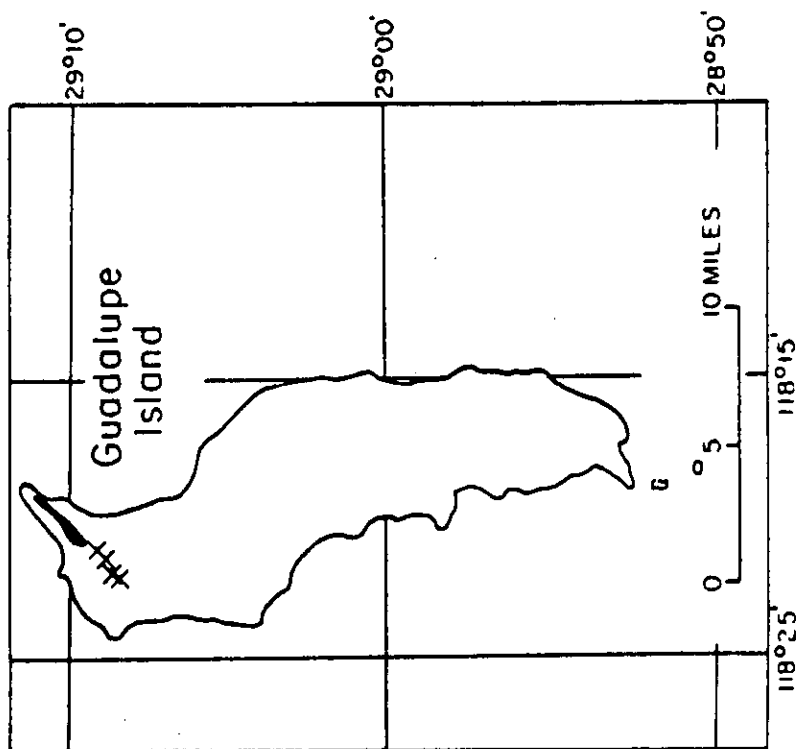


Present Distribution of Monterey Pine Forest at Cambria
Source: Huffman and Associates 1994.



Distribution of Monterey pine on Cedros Island, Mexico.

Source: Crichtfield and Little 1966.



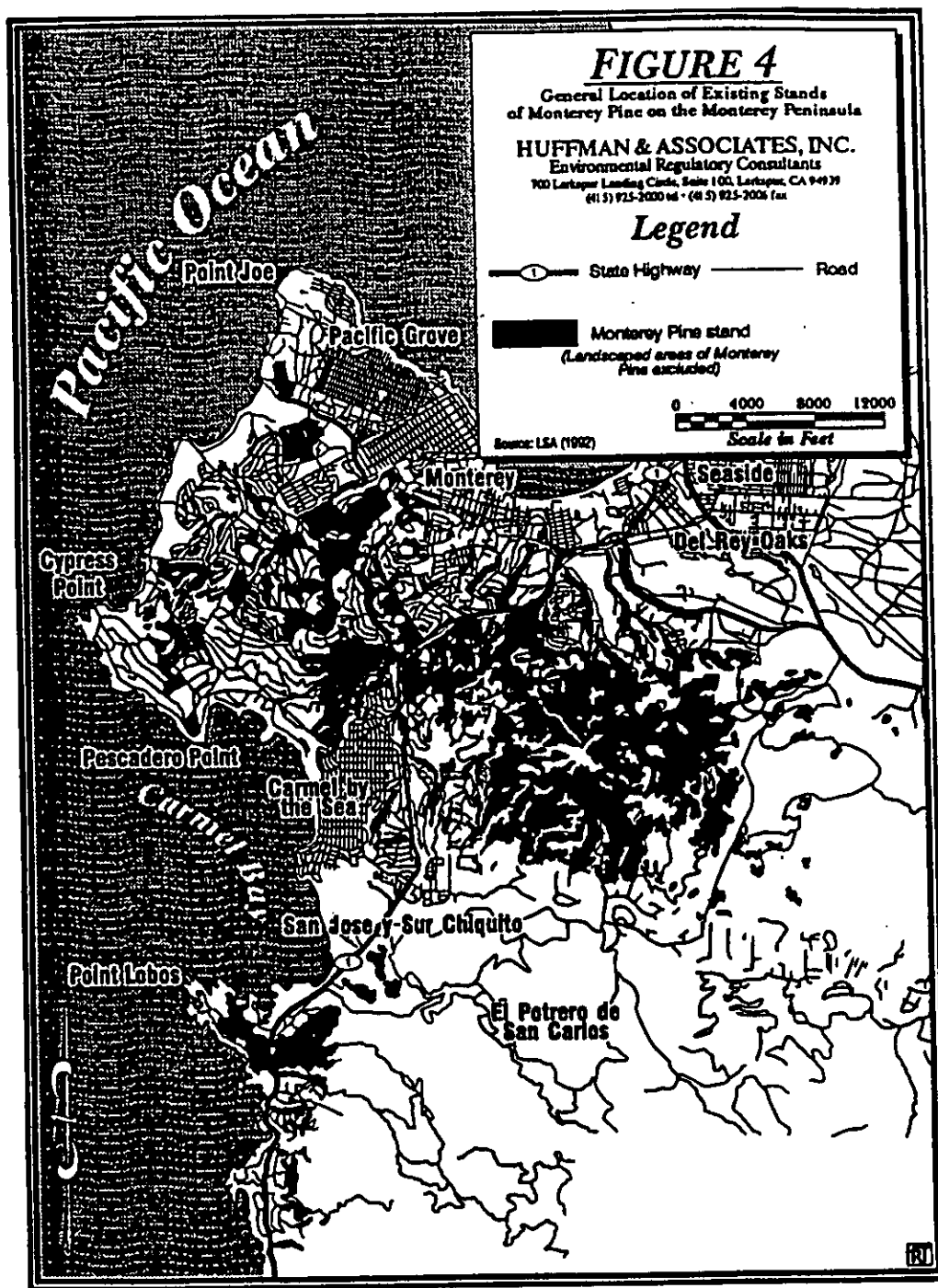
Distribution of Monterey pine on Guadalupe Island, Mexico.

Source: Crichtfield and Little 1966.



Jones & Stokes Associates, Inc.

Figure 7
Distribution of Monterey Pine Forest on Cedros
and Guadalupe Islands, Mexico








Source: Huffman and Associates 1994.



Jones & Stokes Associates, Inc.

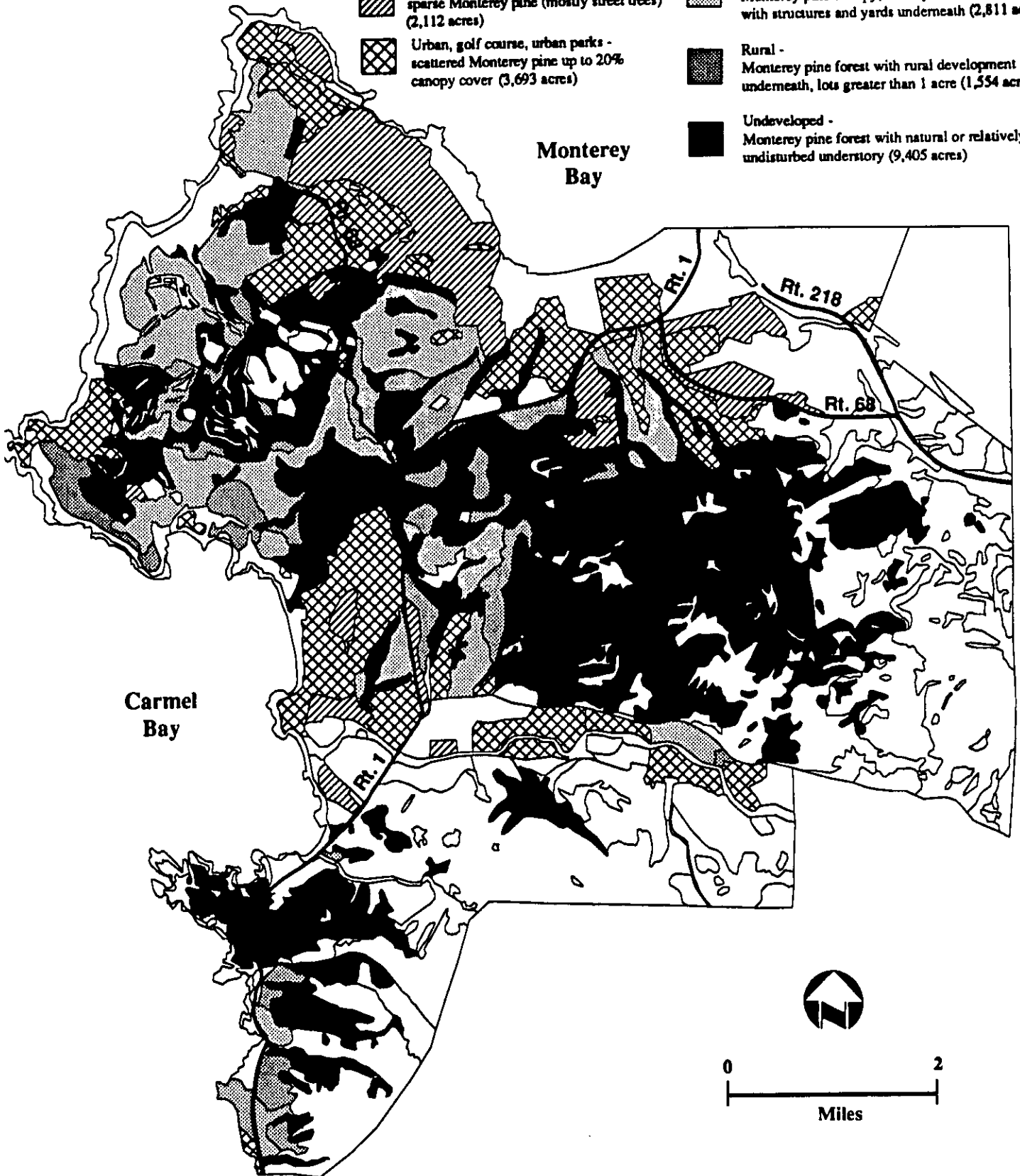
Figure 8
Present Distribution of Monterey Pine
"Native Stands" at Monterey as Mapped
by Huffman and Associates

Legend

-  Urban - sparse Monterey pine (mostly street trees) (2,112 acres)
-  Urban, golf course, urban parks - scattered Monterey pine up to 20% canopy cover (3,693 acres)
-  Suburban - Monterey pine canopy, usually over 20% cover with structures and yards underneath (2,811 acres)
-  Rural - Monterey pine forest with rural development underneath, lots greater than 1 acre (1,554 acres)
-  Undeveloped - Monterey pine forest with natural or relatively undisturbed understory (9,405 acres)

Monterey Bay

Carmel Bay



Jones & Stokes Associates, Inc.

Figure 9
Present Distribution of Monterey Pine Forest
by Land Use

are not in common. Huffman and Associates may have mapped a more restricted category, which would reduce the amount of acreage mapped.

2. More areas of Monterey pine forest were found by Jones & Stokes Associates. Jones & Stokes Associates located more areas of Monterey pine forest, especially in inland areas than were located by Huffman and Associates (1994). Aerial photography used by Jones & Stokes Associates may have been of higher quality in these areas (Culver pers. comm.).
3. Mapping was conducted at different resolution. Jones & Stokes Associates mapped from aerial photographs at a scale of 1" = 1000' with a 5-acre minimum mapping unit size. It appears that Huffman and Associates (1994) mapped at a finer resolution (1-acre minimum mapping unit) and pulled out smaller habitat patches than Jones & Stokes Associates (Deghi and Culver pers. comms.). Excluding smaller patches of other habitats within Monterey pine forest would reduce the amount of forest acreage calculated.
4. Mixed stands of Monterey pine and redwood or Douglas fir in inland areas were mapped by Jones & Stokes Associates. Jones & Stokes Associates mapped as Monterey pine forest sites dominated by Monterey pine, but supporting some component of coast redwood and Douglas fir. These areas may not have been mapped by Huffman and Associates (1994).

Huffman and Associates (1994) estimate the historical extent of Monterey pine to have been between 11,000-12,000 acres at Monterey, 3,500 acres at Cambria, and 1,500 acres at Año Nuevo (Figures 3, 5, and 6). The southern part of the forest at Año Nuevo is estimated to have increased by 235 acres because of human influence (Griffin pers. comm. cited in McDonald and Laacke 1990). Jones & Stokes Associates' estimates of the historical extent of Monterey pine forest at Monterey, based on geomorphic surfaces, are 18,324 acres (Table 1). See Jones & Stokes Associates (1994a) for descriptions of geomorphic surfaces and Table 1 for method of analysis to estimate historical extent.

Significant differences exist between the estimates of historical extent of Monterey pine forest at Monterey calculated by Jones & Stokes Associates and Huffman and Associates (1994). Because Jones & Stokes Associates found more extant forest, it is not surprising that a greater estimate was made for historical forest. Huffman and Associates' (1994) methods are not clearly defined. Jones & Stokes Associates used an electronic planimeter to measure the extent of forest mapped by McDonald (1959), Ford (1964), and Roy (1966) (Figures 4 and 5). The McDonald map shows about 16,000 acres of forest area and excludes historically forested areas of Monterey, New Monterey, and Pacific Grove (Figure 4). The Roy map shows about 14,000 acres of forest and excludes the historically forested areas of Carmel, Monterey, New Monterey, and Pacific Grove, which amount to about 2,000 acres (Figure 5). The Ford map shows about 10,500 acres of forest and does not include large areas of the inland forest or any of the historically forested urban areas. Although this is a crude method, the result of this analysis lend support to the Jones &

Table 1. Estimate of Historical Extent of Monterey Pine Forest
by Geomorphic Surface

Geomorphic Surface	Area (acres) ^a
Marine terrace 2	1,087
Marine terrace 3	1,339
Marine terrace 4	1,547
Marine terrace 5	1,277 ^b
Marine terrace 6	261
Undetermined marine terraces	325 ^c
Middle-aged dunes	828
Oldest dunes	1,168
Inland shale	5,965 ^d
Inland granite	2,419 ^e
Other surfaces	1,553 ^f
Undetermined surfaces	<u>555^g</u>
Total historical extent	18,324

^a Estimates of the extent of historical Monterey pine forest are based on the total extent of the geomorphic surface within the area shown in Figure 4 of Jones & Stokes Associates (1994a), except where otherwise noted.

^b Existing pygmy forest (216 acres) on marine terrace 5 not included in total.

^c Based on relative landscape positions, these undetermined marine terraces are most likely marine terraces 5 and 6.

^d Estimate based on present extent of Monterey pine occurrence on pre-Quaternary shale.

^e Estimate based on present extent of Monterey pine occurrence on pre-Quaternary granitics.

^f Estimate based on present extent of Monterey pine forest in undeveloped or rural areas on geomorphic surfaces not listed above, mostly landslide deposits on shale.

^g Sites that support Monterey pine forest that are outside of the areas mapped by Dupré (1990). Estimated acreage is the total present extent of Monterey pine occurrence.

Stokes Associates conclusion that the extent of the forest at Monterey historically was close to the estimate of 18,324 acres.

Approximately 400 Monterey pine were found on Guadalupe Island in 1964 at a single major population on the north end of the island (Libby et al. 1968). This population occurs along about 5 linear miles of ridge tops and is probably less than 0.5 mile wide at its widest part (Figure 7). Based on the age structure of the population and descriptions of the forest from the late 1800s, Libby et al. (1968) concluded that the Guadalupe populations have been greatly reduced as a result of browsing by introduced goats. Monterey pine populations on Guadalupe Island have declined precipitously and only 45 trees were counted in spring 1988 (Libby 1990).

Libby et al. (1968) estimated about 85,000 mature trees occurred on Cedros Island with dense occurrences of seedlings and saplings. These forests cover an area of about 370 acres (Figure 7).

Plantings in California and Elsewhere in North America

Monterey pine is planted for ornamental purposes and for Christmas tree farms throughout lowland and foothill California. It is planted as far south as San Diego and as far north as Vancouver, Canada. It has also been planted in the southeastern United States.

Plantings Worldwide

Monterey pine is planted and grown for lumber and pulp in many parts of the world, especially in the southern hemisphere at similar latitudes as its natural occurrences. Monterey pine is a major forest plantation tree in New Zealand, Chile, Australia, Spain, South Africa, Argentina, Uruguay, and Kenya (Roy 1966, McDonald and Laacke 1990). In the 1950s, the area of planted Monterey pine forest in New Zealand, Chile, Australia, Spain, and South Africa was estimated to be 1.55 million acres (Scott 1960). The acreage of Monterey pine plantations in Australia increased fivefold between 1950 and 1974, from about 180,000 acres to 900,000 acres (Brown 1976). Based on allozyme studies, Moran and Bell (1987) conclude that most of the Monterey pine in Australia originated from the Monterey and Año Nuevo populations; the Monterey pine in New Zealand also originated from the Monterey and Año Nuevo populations (Libby pers. comm.)

REPRODUCTIVE BIOLOGY

Pollination

As is typical of pines, Monterey pine is monoecious, having male and female cones on the same tree. Pollen is carried on the wind from male to female cones on the same or different trees. Monterey pines are self-compatible (able to pollinate themselves and produce seed from their own pollen) (Roy 1966). Monterey pine sheds pollen in late winter or early spring. Female cones are pollinated most effectively during about a 2-week period after they first open (Roy 1966).

Seed Production and Dispersal

Seeds mature in the cones the second autumn following pollination. Monterey pine produces an abundance of seeds annually (Sudworth 1967). Each cones produce about 150-200 seeds and an average-sized tree produces about 6,000 cones over several years, resulting in over 1 million seeds (Scott 1960, Coleman 1905, Roy 1966). The viability of seeds is high, ranging from 70-94%, and seeds remain viable for many years in closed cones on the tree (over 10 years) or in proper storage (over 20 years) (Roy 1966, Sudworth 1967, Scott 1960).

At maturity, cones remain on the tree for many years and usually are closed. On hot, dry days many cones will partially open, drop some seed and then reclose (Roy 1966, Scott 1960). Repeated opening and closing of cones produces a steady seed rain through the year and from year to year. Cones exposed to the sun may open fully. Heat from fire dries cones to the point of complete opening and seed release.

Some animals that feed on Monterey pine seeds may be effective seed dispersers if they occasionally drop seeds before they can consume them or if they cache (hide seeds, usually in clusters in the ground) seeds and then do not relocate the cache. Animals that feed on Monterey pine seeds include common crow, Steller's jay, scrub jay, California mouse, deer mouse, dusky-footed woodrat, California ground squirrel, western gray squirrel, western spotted skunk, striped skunk, raccoon, and gray fox (Roy 1966, Coleman 1905).

On many sites, seeds are present on the ground at all times, waiting for the appropriate cues and conditions to germinate (Coleman 1905). Seeds will germinate without stratification, but stratification under cold, moist conditions enhances germination (McDonald and Laacke 1990).

GROWTH

Seedlings

Seedlings begin growth by putting down a taproot, but taproot growth is not persistent (Scott 1960, Roy 1966). On coarse-textured, rich soils, many side roots branch from the taproot and mycorrhizal fungi associations are initiated (Roy 1966). Seedlings do best on moist mineral soils, but can also grow in needle litter several inches thick (Scott 1960). Full sunlight provides optimal conditions for seedling growth, but seedling survival may be most limited by soil moisture (Roy 1966). Sites cleared by fire or by clearcutting support large numbers of seedlings at high density (Roy 1966, McDonald and Laacke 1990). Clearcut areas can support 1,000-10,000 seedlings per acre within 2 years (Roy 1966). In Monterey, regeneration in clearcuts is high, even on poor soils (McDonald 1959). In New Zealand, up to one million seedlings per acre have been counted in fire-killed stands of pine (Roy 1966). It is not unusual for seedlings to be over 12 inches tall after 1 year and 3-year-old trees are usually 3-6 feet tall (Roy 1966).

Saplings

Monterey pine is a very fast growing tree, adding 3-4 feet in height each year and, in good conditions, 8 or more feet per year (Scott 1960). A tree in Australia was recorded to have added 20 feet in height in its fifth year (Roy 1966). By 5 years of age, the lateral root system is more extensive than the taproot (McDonald and Laacke 1990). Growth begins to slow at about 15 years of age (Scott 1960).

Mature Trees

Monterey pine is a short-lived tree, attaining full size in 80-100 years and probably does not often live more than 150 years (Sudworth 1967). Female cones may be produced as early as 5-10 years of age, but yields do not become substantial until 15-20 years of age (Coleman 1905, McDonald and Laacke 1990, Scott 1960). Each year's growth usually produces one to five pseudowhorls of branches and cones (Scott 1960). Growth slows greatly at about 35 years of age (Scott 1960). The crown may remain pointed for 35-45 years and then becomes flat topped as the growth rate declines (Roy 1966). On good sites, in 80-90 years pines will reach a height of 120 feet and a diameter of 2-4 feet (Scott 1960). The typical size for Monterey pine is 70-110 feet tall and 2-3 feet dbh (Roy 1966). Adult root systems are shallow and widespread with most roots in the top foot of soil and few deeper than 2 feet (Roy 1966).

Annual grow begins in February or March when the mean temperature exceeds 51-53°F (Roy 1966). Growth usually stops in September or October as available soil moisture is depleted and low winter temperatures prevent the resumption of growth even with winter rainfall (Roy 1966).

Dense stands of Monterey pine self-thin as some individuals outgrow and overtop others (Roy 1966). Lower branches die as they are shaded and trunks may not support live branches for 25-50 feet (Roy 1966). Trees at the forest edge in Monterey are often stunted (McDonald 1959).

Some evidence indicates that Monterey pine may grow faster and attain greater heights at Cambria than at Monterey (Scott 1960). An age-to-dbh graph generated from data in McDonald (1959) is provided in Figure 10.

SYSTEMATICS/TAXONOMIC RELATIONSHIPS

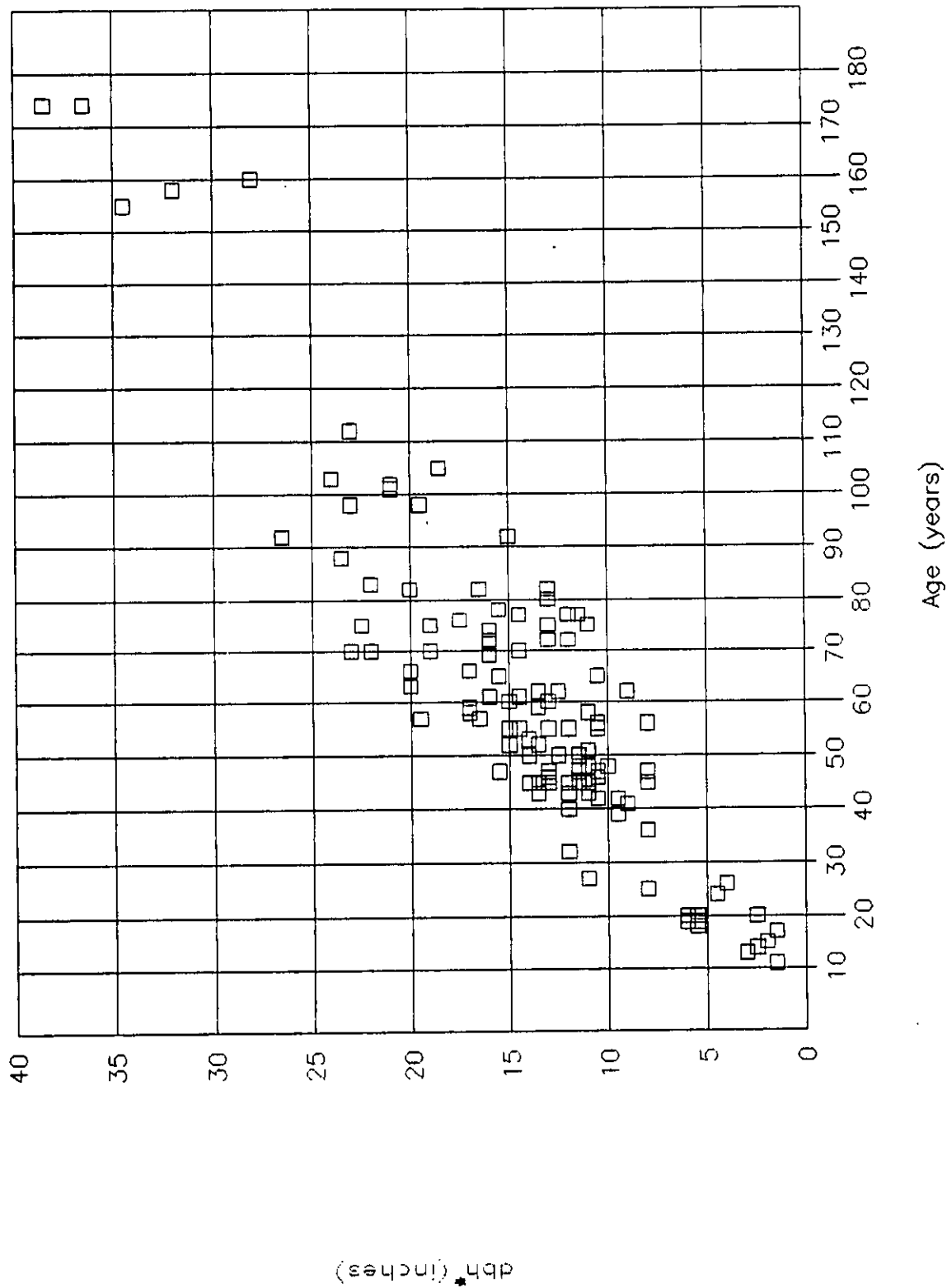
Evolutionary History

Monterey pine fossils date from the early Miocene Epoch and the species is likely even older (Axelrod 1967). Cedros Island pine, with small cones and needles in clusters of two, is considered the most primitive form of Monterey pine (Axelrod 1980). Axelrod (1980) believes that the Guadalupe Island pine colonized Guadalupe Island from the mainland during the Pliocene Epoch. Guadalupe Island is a volcanic island about 175 miles from the mainland and is estimated to be 7 million years old (Moran et al. 1988).

The evolutionary relationship between the five natural stands of Monterey pine has been predicted using allozyme studies (Moran et al. 1988, Plessas and Straus 1986). The genetic distance is greatest between the Mexican island populations and the California mainland populations (Moran et al. 1988). This result conforms with the large morphological differences between island and mainland types. However, the evolutionary relationships between the three California populations is in dispute. Moran et al. (1988) conclude that the Monterey and Año Nuevo populations are the most closely related. Plessas and Straus (1986) conclude that the Monterey and Cambria populations are most closely related.

Related Species

Monterey pine is classified in the *Oocarpae* subsection of the genus *Pinus* (Critchfield and Little 1966). This subsection includes seven species: Monterey pine, Bishop pine, knobcone pine, Mexican weeping pine (*Pinus patula*), Gregg pine (*Pinus greggii*), oocarpa pine (*Pinus oocarpa*), and Pringle pine (*Pinus pringlei*). Bishop pine ranges from northern



* dbh = diameter at breast height

Source: Based on data from McDonald 1959.

Figure 10
Relationship Between Age (Annular Rings) and Trunk Diameter
at Breast Height for Monterey Pine

Jones & Stokes Associates, Inc.



California to central Baja California and Cedros Island. Knobcone pine ranges from central Oregon to northern Baja California. Mexican weeping pine, Gregg pine, and Pringle pine all occur in the mountains of Mexico. Oocarpa pine ranges from northern Mexico to Nicaragua.

The species considered to be most closely related to Monterey pine are knobcone pine and Bishop pine. Knobcone pine is known to hybridize with Monterey pine and the hybrid is called *Pinus radiata x attenuata*. Natural hybrids occur at Año Nuevo. Bishop pine has been reported to hybridize with Monterey pine (Stebbins 1950), but natural hybridization between these two species is probably uncommon (Griffin 1972) or may not occur at all (Millar and Critchfield 1988). At Monterey, pollen dispersal in Monterey pine occurs in February and in Bishop pine occurs in April. This separation of pollen dispersal periods makes natural hybridization between Monterey and Bishop pine unlikely (Stebbins 1950).

Within-Species Variation

Cone Size and Shape

Cambria populations have larger cones than other populations (Scott 1960, Ford 1964). Average cone length in Monterey pine populations increases in the following order: Cedros, Guadalupe, Monterey, Año Nuevo, Cambria (Axelrod 1980, Ford 1964). Cones from California populations tend to be more asymmetrical than those in Mexican populations (Axelrod 1980).

Some evidence indicates that larger cones produce larger seeds (Ford 1964, Roy 1966). Large seeds have been shown to produce faster growing seedlings (Griffin 1975). Larger seeds may have the advantage of greater embryo food stores necessary in the drier climate of Cambria relative to Monterey and Año Nuevo (Axelrod 1980).

Cold Tolerance

Tolerance to cold has been shown to be genetically controlled and varies within the species in the expected south to north trend, with cold tolerance in order from least to greatest: Cambria, Monterey, Año Nuevo (Hood and Libby 1980).

Tap Root Persistence

In Cambria populations the tap root is persistent and may be found in trees 40-60 years old, as opposed to Año Nuevo and Monterey populations where the taproot is not persistent (Lindsay 1937, Scott 1960). Evidence indicates that the taproot is persistent in some Monterey trees growing on deep soils (McDonald and Laacke 1990).

Susceptibility to Western Gall Rust

Western gall rust (*Peridermium* [= *Endocronartium*] *harknessii*) is common on Monterey pine in California. This fungal disease causes globose galls to form on branches and stems. Monterey pine from Monterey and Cambria are the most susceptible to western gall rust attack, pines from Año Nuevo are intermediate in susceptibility, and pine from Guadalupe and Cedros are the least susceptible (Old et al. 1986). Only the Monterey population shows a significant amount of within-population variation in gall rust susceptibility (Old et al. 1986).

Susceptibility to Red-Band Needle Blight

Monterey pine seedlings from Cedros and Guadalupe populations are apparently less susceptible to red-band needle blight (*Mycosphaella* [= *Scirrhia*] *pini* [= *Dothistroma septospora*]) than are those from California populations (Libby et al. 1968). Red-band needle blight is found in Monterey pine plantations in the Pacific northwest, but is not found in native stands (McDonald and Laacke 1990).

Growth and Form

After nine growing seasons, Guinon et al. (1982) found greater variation in the growth and form of common garden-grown clones derived from Cambria and Año Nuevo stock than among clones from Monterey stock.

Allozyme Variation in Enzyme Systems

Moran et al. (1988) measured allelic frequencies at 27 loci in the five natural populations of Monterey pine. Plessas and Straus (1986) measured allelic frequencies at 37 loci in the three California populations of Monterey pine. The Monterey population is the most genetically diverse population with more alleles per locus and more polymorphic loci than any of the other four populations (Moran et al. 1988). Allozyme variation among populations of Monterey pine is greater than within populations, with the greatest differences between the island and mainland populations (Moran et al. 1988, Plessas and Straus 1986). In contrast, widespread wind-pollinated forest tree species typically have lower genetic variation among populations than within populations (Moran et al. 1988, Plessas and Straus 1986). The genetic differences among populations of Monterey pine is not surprising considering the long period of genetic isolation among the five populations. Within populations of Monterey pine, each stand supports greater genetic variation than that found among stands (Libby pers. comm.). This relatively high variation within stands is indicative of widespread gene flow within the population. Long-distance gene flow is likely through wind dispersed pollen rather than seed dispersal. Based on the results of allozyme studies, the maintenance of just a few stands within a population could theoretically preserve most of the genetic variation of the entire population.

Compared to other pine species, the genetic diversity in Monterey pine enzyme systems is moderate to low (Brown and Moran 1981, Moran et al. 1988, Plessas and Straus 1986, Adams 1983). Monterey pine's closest relatives, knobcone and Bishop pine, are lower in genetic diversity (Moran et al. 1988).

ASSOCIATED SPECIES

Año Nuevo

At Año Nuevo, Monterey pine occurs associated with Douglas fir (*Pseudotsuga menziesii*), coast redwood (*Sequoia sempervirens*), knobcone pine (*Pinus attenuata*), coast live oak (*Quercus agrifolia*), madrone (*Arbutus menziesii*), and ponderosa pine (*Pinus ponderosa*) (McDonald and Laacke 1990, Roy 1966, Coleman 1905, Scott 1960). Some natural hybrids occur between Monterey pine and knobcone pine (Griffin and Critchfield 1972).

Important understory species include bracken fern (*Pteridium aquilinum*), poison-oak (*Toxicodendron diversiloba*), coyote brush (*Baccharis pilularis*), blueblossom (*Ceanothus thyrsiflorus*), California wax-myrtle (*Myrica californica*), California coffeeberry (*Rhamnus californica*), California blackberry (*Rubus ursinus*), and California sagebrush (*Artemisia californica*) (McDonald and Laacke 1990, Roy 1966, Scott 1960).

Monterey pine forest at Año Nuevo is not as clearly defined as at Monterey and Cambria. Pure stands occur here, but Monterey pine more often occurs in mixed stands with coast redwood on lower, mesic slopes; Douglas fir on middle slopes; and knobcone pine on upper, dry slopes with shallow soils (see Ford 1964 map in Figure 3) (Roy 1966). Stands dominated by Monterey pine are typically on drier, southfacing slopes on the seaward edged of the forest (Roy 1966). The largest Monterey pines grow with Douglas fir on mesic, northfacing slopes with deep soils (Roy 1966).

Surrounding vegetation of the Año Nuevo Monterey pine forest includes Douglas fir forest, redwood forest, and mixed evergreen forest.

Monterey

At Monterey, Monterey pine grows with coast live oak in most stands, Monterey cypress (*Cupressus macrocarpa*) near the coast, and Bishop pine and gowen cypress (*Cupressus goveniana* var. *goveniana*) on Huckleberry hill and near Gibson Creek. Coast redwood (*Sequoia sempervirens*), white alder (*Alnus rhombifolia*), Scouler's willow (*Salix scouleriana*), and arroyo willow (*Salix lasiolepis*) occur with Monterey pine in riparian habitats (McDonald and Laacke 1990, Roy 1966, Coleman 1905). A detailed description

of Monterey pine forest species associations and geographic vegetation patterns at Monterey is provided in Jones & Stokes Associates 1994a.

Important understory shrubs include shaggy-barked manzanita (*Arctostaphylos tomentosa*), California huckleberry (*Vaccinium ovatum*), bush monkeyflower (*Mimulus aurantiacus*), California blackberry, poison-oak, and creeping snowberry (*Symphoricarpus mollis*) (Vogl et al. 1988, McDonald and Laacke 1990, Roy 1966).

To the interior, Monterey pine forest is surrounded by coast live oak woodland, grassland, chaparral, and coastal sage scrub. In the Santa Lucia Mountains, Monterey pine forest is replaced by coast redwood-Douglas fir forest. In these interior areas, Monterey pine prefers more mesic northfacing slopes and ravines (Scott 1960). On the coast, Monterey pine forest is replaced by Monterey cypress forest, northern coastal scrub, dune scrub, and coastal prairie.

Cambria

At Cambria, Monterey pine grows with coast live oak. Understory species include bracken fern, California blackberry, poison-oak, California sagebrush, coyote brush, and bush monkeyflower (McDonald and Laacke 1990, Roy 1966). On drier sites, coast live oak is common and the understory supports a dense cover of shrubs (Roy 1966). On drier, south-facing slopes California sagebrush is more common in the understory (Scott 1960). On more mesic sites the pines form dense stands with fewer oaks and an understory of ferns, grasses, and low shrubs (Roy 1966).

Grassland surrounds the Monterey pine forest at Cambria, with Monterey pine preferring the more mesic north-facing slopes (Scott 1960).

Guadalupe

On Guadalupe Island, Monterey pine grows with island live oak (*Quercus tomentella*) and Guadalupe palm (*Brahea* [= *Erythea*] *edulis*) (Libby et al. 1968). The understory is open and grassy. Monterey pine forest occurs at the north end of the island and is restricted to ridgetops and upper portions of slopes that face the prevailing northwesterly winds. The pine forest occurs between about 1,000-3,800 feet elevation (Libby et al. 1968). Some woody species on Guadalupe Island that may occur with Monterey pine are Guadalupe cypress (*Cupressus guadalupensis*), California juniper (*Juniperus californicus*), manzanita (*Arctostaphylos* sp.), island ceanothus (*Ceanothus insularis*), and coffeeberry (*Rhamnus pirifolia*) (Axelrod 1980).

Cedros

On Cedros Island, Monterey pine grows with yucca (*Yucca* spp.) and cactus (*Opuntia* spp.) (Libby et al. 1968). Monterey pine on Cedros Island occur on windward-facing ridge tops and mountain slopes and in moist canyons in two major populations at the north end and in the central part of the island (Libby et al. 1968). Pine forests occur between about 900-2,100 feet elevation (Libby et al. 1968). Some woody species that occur on Cedros Island and may occur with Monterey pine are juniper, (*Juniperus cerroensis*), chamise (*Adenostoma fasciculata*), ceanothus (*Ceanothus verrucosus*), cneoridium (*Cneoridium dumosum*), toyon (*Heteromeles arbutifolia*), Cedros oak (*Quercus cedrosensis*), and island coffeeberry (*Rhamnus insula*) (Axelrod 1980).

SOILS AND ROOTS

A summary of the soil preference of Monterey pine is presented by Scott (1960) from Lindsay (1937):

1. Monterey pine grows on soils derived from various kinds of parent rock.
2. To reach a height of 100 to 120 feet, Monterey pine needs at least 3 to 4 feet of soil. Where bedrock outcrops or nears the surface, the tree grows to only 70 feet or less in height.
3. Sandy loams and fine sandy loams favor Monterey pine. Clay soils do not suit it, normally.
4. Monterey pine does not generally occur on poorly drained soil.
5. Relative to chaparral shrubs, coast live oak, and grass, Monterey pine is more exacting as to soil; but it is less exacting than ponderosa pine and Douglas fir, growing on shallower and less productive soils.
6. Where Monterey pine reaches 80 feet or more in height, the humus development is very good, better than most conifers in the western United States. On poor sites, only 1 to 2 inches of dry pine needle litter develop.
7. Shallow soils restrict the growth and occurrence of Monterey pine. At Monterey and Cambria, it grows mainly, or best, on sandy loam. At Año Nuevo, Monterey pine favors the Diablo soil type (the name "Diablo" is no longer applied to these soils).

These Monterey pine forest soil characteristics described by Lindsay (1937) have been repeated in subsequent literature (Scott 1960, Roy 1966, MacDonald and Laacke

1990). Some of these generalizations hold true, but some are not verified by the field research conducted by Jones & Stokes Associates as part of this study (Jones & Stokes Associates 1994a). Detailed descriptions of soils that support Monterey pine at Monterey are provided in Jones & Stokes Associates 1994a.

Monterey pine roots rarely penetrate deeper than 2 feet, even on good soils, but lateral roots in the top 12 inches of soil are extensive and strong (Lindsay 1937, Scott 1960). The root system may extend 30-40 feet from the trunk (Roy 1966). A dense clay layer typically restricts root growth to shallow depths, but in deep soils, some roots may penetrate to depths of 5.5 feet (McDonald and Laacke 1990). Small feeder roots become extensive in the surface layer of organic matter, where present (McDonald and Laacke 1990). Monterey pine seedlings begin life with a taproot, but it does not usually last (Scott 1960).

Mycorrhiza fungi associate with Monterey pine roots. Fruiting bodies of *Boletus* sp. and *Amanita* sp. are often found with Monterey pine in all three California populations (Offord 1964).

FIRE HISTORY, FIRE ECOLOGY, AND ECOLOGICAL SUCCESSION

Fire Ecology and Ecological Succession

Fire causes Monterey pine cones to open, clears overstory and understory cover, and returns nutrients to the soil. Following fire, thousands or millions of seedlings per acre often establish simultaneously. Fire-scarred trunks on older trees and direct evidence from recent fires indicate that many mature trees survive groundfires.

Scott (1960) described the successional sequence at Año Nuevo as follows. Young pine stands support an understory of dense bracken fern, blackberry, and young coast live oak. On poor soils the young pine stands support a shrub understory. Older pine stands support a continuous layer of blackberry, bracken fern, poison-oak, and grass. In the absence of fire at Año Nuevo, Douglas fir and coast redwood would likely outcompete Monterey pine for light and space except on poor soils and possibly on coastally exposed slopes.

At Monterey, direct observations of secondary succession following recent fires indicate that shrub and herb diversity is greatest in early succession stages; the dominant species of mature forest reestablish simultaneously with the other species; and as dominant trees and shrubs mature, species diversity declines (Jones & Stokes Associates 1994a). For descriptions of successional patterns following burns for different Monterey pine forest subtypes see Jones & Stokes Associates 1994a.

Fire History

Fire data for the Monterey Peninsula maintained by the City of Monterey Fire Departments and California Department of Forestry and Fire Protection were not sufficient to create a fire history map showing the limits and dates of burns in Monterey pine forest. Extensive burning in Monterey pine forest occurred in the latter half of the 19th century (McDonald 1959). Major fires on the Monterey Peninsula in the 20th century have occurred in 1904, 1924, 1959, and 1987. The 1904 fire occurred in the fall and burned about 2,000 acres in the Huckleberry Hill area (Taylor 1987). The 1924 fire burned about 100 acres (Taylor 1987). The 1959 fire occurred in June on the west slope of Huckleberry Hill and burned about 62 acres (Taylor 1987). The 1987 fire started on May 31, 1987, and burned over 200 acres on the west slope of Huckleberry Hill (Taylor 1987). The general location of this 1987 fire is shown as polygon number 44 in Appendix A. The area of the 1987 fire likely included parts of the area burned in 1959. Forest stands established after the 1959 fire occur on the north edge of the 1987 burn site (see Appendix A). In 1990, a burn of about 8 acres in extent occurred October 8 on either side of Route 68, at the south end of the Presidio of Monterey (Rodewald and Staub pers. comm.). The general location of this fire is shown as polygon 43 in Appendix A.

Greenlee and Langenheim (1990) estimated the mean fire intervals for various habitats in the Monterey Bay area under different historic fire regimes. They conclude that, due to fire suppression, fire frequencies in forested habitats (redwood forest and mixed evergreen forest) were lower in recent times (1929-present) than in any past period. They also conclude that under a natural lightning-start fire regime (before 11,000 years ago) fire frequencies in forested habitats were lower than fire frequencies in fire regimes imposed by native Americans (11,000 years ago to 1792), Spanish colonists (1792-1848), or northern European colonists (1848-1929).

DISEASES AND PESTS

Fungal Diseases

Offord (1964) lists 72 pathogens that affect native stands of Monterey pine. The major diseases affecting California's native stands and plantations are western gall rust (*Peridermium harknessii*), coast gall rust (*Peridermium cerebroides*), annosus root rot (*Heterobasidion annosum* [= *Fomes annosus*]), shoestring fungus rot (*Armillaria mellea*), and velvet top fungus (*Polyporus schweinitzii*) (Offord 1964, Roy 1966, McDonald and Laacke 1990). Western gall rust and coast gall rust are fungal diseases that attack the stem. Both of the gall rusts result in retardation of stem growth, death of small trees, witch's-brooms, and spherical stem galls, with the galls of western gall rust also exhibiting exfoliating bark. Annosus root rot, shoestring fungus rot, and velvet top fungus are fungal diseases of the root system. Annosus is the most important root disease on Monterey pine, killing trees most

often where they grow on shallow, poorly drained, and heavy soils (Offord 1964). Shoestring fungus also attacks oak stumps and is more common on Monterey pine where oaks are present, but losses of Monterey pine to shoestring fungus are minor (Offord 1964, Hepting 1971). Velvet top fungus kills fast-growing pole-sized and young trees on good soils (Offord 1964). Velvet top fungus is common at Monterey, Año Nuevo, and Swanton.

Monterey pine seedlings are very hardy, are only affected by damping-off under extreme conditions, and appear to be little affected by diseases in general (Offord 1964, Hepting 1971). Monterey pine appear to be more affected by diseases where they grow on shallow and poorly drained soils (Offord 1964).

Pitch Canker Infestation

Pitch canker (*Fusarium subglutinans*) has recently become prevalent in planted stands of Monterey pine in California and may be present in indigenous stands (Adams 1989, Storer and Dallara 1992, McCain et al. 1987). In the early 1960s, Hepting (1961) noted that pitch canker attacked Monterey pine planted in the eastern United States vigorously and lethally and Offord (1964) warned that pitch canker "should be regarded as potentially dangerous to Monterey pine both native and exotic." In 1986, pitch canker was recognized as the cause for large-scale die-back of several thousand trees in nonindigenous stands of Monterey pine in Santa Cruz County (McCain et al. 1987, Scharpf 1993). Symptoms of pitch canker include dead branch tips, dead branches, top kill, and abundant resin flow from branches and trunk (McCain et al. 1987, Scharpf 1993). Wounds are required for infection to occur and insects are known to carry the spore (Scharpf 1993).

Pitch canker in Monterey pine has been found in planted stands, Christmas tree farms, and nurseries in Alameda, Santa Cruz, Monterey, San Benito, Los Angeles, San Diego, San Luis Obispo, and Santa Barbara Counties (Adams 1989, Storer and Dallara 1992). The largest infestations are in Alameda and Santa Cruz Counties (Storer and Dallara 1992). Susceptibility to pitch canker is highly variable among individuals of Monterey pine, with some trees apparently resistant (Adams 1989).

Pitch canker was first detected on the Monterey Peninsula at Asilomar State Conference Grounds around 1990 and currently infects Monterey pines in five Peninsula locations. The fungal disease first infected planted trees, but has recently moved into native stands; it affects both old and young trees. (Smith and Wood pers. comms.) The Peninsula's largest concentration of pitch canker damage is in the northwest section of Carmel where it has infected approximately 25% of the pines (Kelly pers. comm.).

The pitch canker fungus usually infects branch tips, causing them to wilt and die. It also infects tree trunks, limbs, and roots, resulting in resinous cankers (Storer and Dallara 1992.) Although pitch canker alone seldom kills trees, the disease is frequently associated with other forest pests (e.g., bark beetles), which in combination can inflict mortality. Mechanisms by which Monterey pines are infected and injured through pitch canker infection are complex, often involving not only bark beetles, but their insect predators.

Although some Monterey pine trees display resistance to the disease, the source of such resistance is currently poorly understood. Whether native trees are inherently more resistant than planted trees is uncertain because of the limited occurrence of the disease to date in native stands (Wood pers. comm.).

As of spring 1994 at Monterey, pitch canker has been found in about 200 trees in Carmel; about 150 trees at the Asilomar Conference Grounds; and in Pacific Grove, Monterey, and Del Monte Forest (Figure 11) (Huffman and Associates 1994, Staub and Kelly pers. comms.). At Año Nuevo, pitch canker is found in planted pine along roads that bisect the native stands of Monterey pine (Adams 1989).

Mistletoe

Coastal dwarf mistletoe (*Arceuthobium littorum*) is a stem parasite common on Monterey pine (Offord 1964). Coastal dwarf mistletoe is most prevalent at Cambria, common at Monterey, and uncommon at Año Nuevo (Offord 1964, Scott 1960). Dwarf mistletoe can weaken trees and make them more susceptible to insect attack (Hepting 1961).

Insect Pests

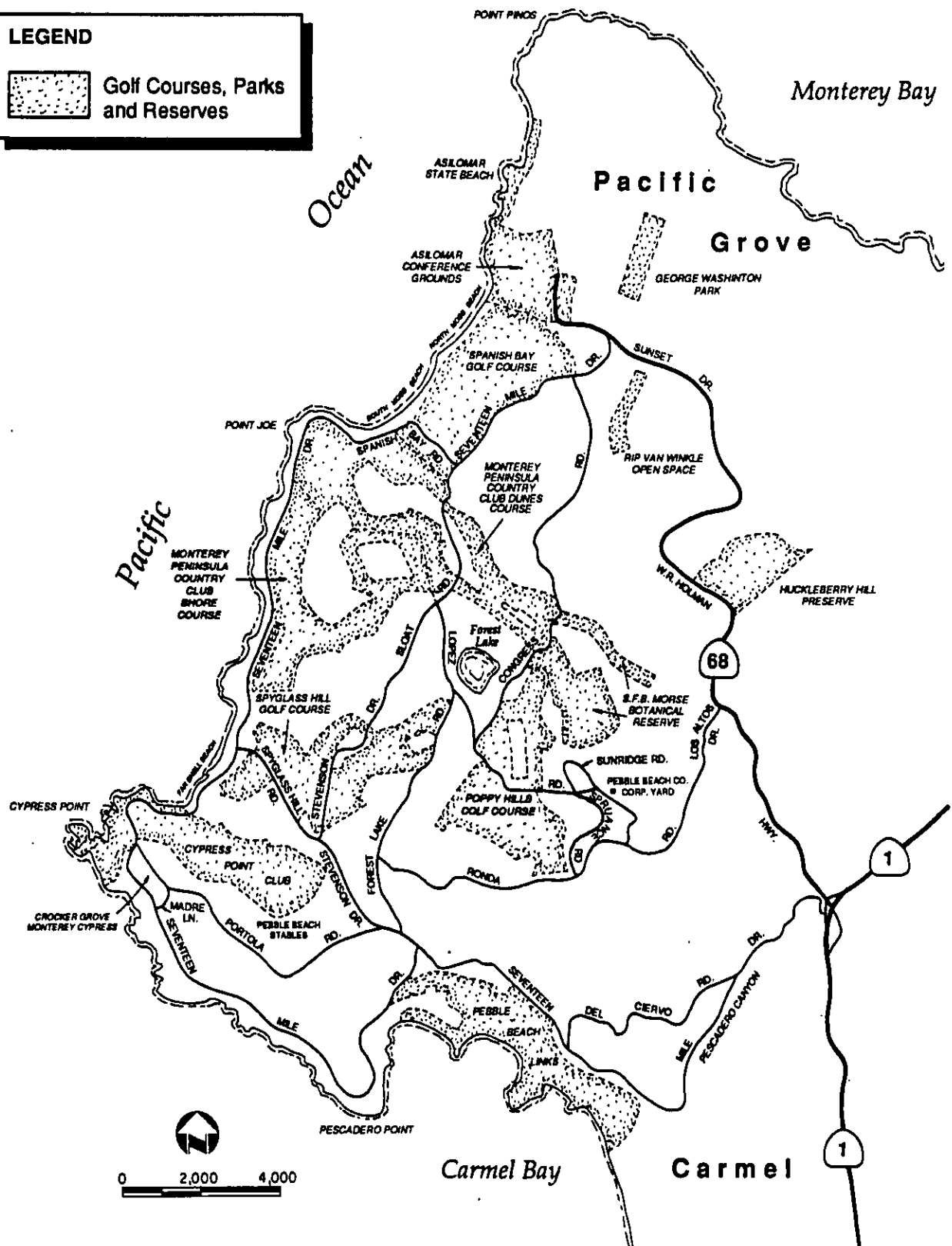
Coleman (1905) identified over 80 insect pests known to occur on Monterey pine, including defoliators, sap suckers, needle miners, twig miners, cambium miners, and wood borers. Furniss and Carolin (1977) list 56 species of insects known to attack Monterey pine. The most damaging insects to native stands of Monterey pine are red turpentine beetle (*Dendroctonus valens*), California five-spined ips (*Ips paraconfusus*), California four-spined ips (*Ips plasotographus maritimus*), Monterey pine ips (*Ips mexicanus* [= *radiatae*]), and Monterey pine weevil (*Pissodes radiatae*) (Roy 1966, Furniss and Carolin 1977). The larvae of red turpentine beetle mine the inner bark mainly of fire-damaged or old trees, but also may infest young healthy trees (Roy 1966, Furniss and Carolin 1977). The ips are also bark beetles. California five-spine and four-spine ips attack mostly saplings and young trees (Roy 1966). Monterey pine ips and California four-spined ips usually attack weakened trees after other bark beetles have already infested them (Roy 1966, Furniss and Carolin 1977). Monterey pine weevil may attack leader shoots but typically mine the inner bark of the trunk and root collar of young trees (Roy 1966, Furniss and Carolin 1977).

COMMERCIAL USES

As discussed above, Monterey pine is extensively planted in New Zealand, Chile, Australia, Spain, South Africa, Argentina, Uruguay, and Kenya. Elsewhere in the world,

LEGEND

 Golf Courses, Parks and Reserves



Jones & Stokes Associates, Inc.

Figure 11
Locator Map for Monterey Peninsula

Monterey pine is mostly known as "radiate pine." Monterey pine is grown mainly for lumber and pulp. Silvicultural techniques and wood quality of Monterey pine have been extensively studied in New Zealand and Australia and hundreds of articles on these topics have been published in the forestry journals. Other than Christmas tree farms and horticultural plantings, Monterey pine is of little commercial value in the United States. Timber companies in New Zealand and Australia have engaged in long-term breeding programs to develop improved genetic lines of Monterey pine for timber-growing purposes. In New Zealand, the major traits selected for are faster growth rate, stem straightness, and increased number of branches of smaller size (Libby pers. comm.).

Monterey pine logs and lumber are important exchange commodities among Pacific Rim nations and important export commodities for New Zealand and Chile. In 1992, the combined value of Monterey pine log and lumber exports from these two nations exceeded \$500 million (Flora pers. comm.). China, Japan, and Korea are the principal importers of Monterey pine forest products. In 1993, in response to restrictions on softwood timber harvesting in the western U.S., Monterey pine logs began being imported to the U.S.

California's native stands of Monterey pine constitute the exclusive repository of raw material for developing genetic innovations in Monterey pine. The industrial Monterey pine forests of New Zealand, Chile, and other foreign nations have been developed through genetic manipulations to display rapid growth and other economically beneficial attributes. The resulting genetic homogeneity of these forests could make them susceptible to catastrophic losses resulting from new diseases or insect pests. Such possibilities underscore the economic importance of maintaining the maximum possible genetic resources for the species within its native stands.

STAND HEALTH

Assessments of the health of forest stands are often subjective insofar as they depend on the desired future condition of the stand or the outputs desired from the stand, which may vary depending on those individuals doing the assessments (Kolb et al. 1994). Based on the criteria of resource sustainability, resistance to agents capable of inflicting catastrophic losses, nutrient recycling rate, and diversity of vegetative structure, however, many of the Monterey pine stands on the Monterey Peninsula appear to be in relatively poor health (McBride, Wood, Staub pers. comms.). The Peninsula's urban stands appear to be healthier than native stands in rural areas (McBride pers. comm.).

The principal sources of poor health among the Peninsula's Monterey pine stands are:

- the advanced age of most trees as compared to a short average life expectancy for Monterey pine (80-90 years) relative to other pines;

- high average stand densities relative to natural stands under prehistoric fire regimes and to stands historically managed for lumber and firewood production, resulting in elevated intertree competition, low regeneration rates, low nutrient recycling rates, and dangerous fuel loadings;
- persistent drought over the past 8 years; and
- the emergence and establishment of pitch canker, a fungal disease that interacts with bark beetles and other endemic forest pests to kill trees, and which could result in widespread mortality within the Peninsula's Monterey pine stands (Kelly and Wood pers. comms.).

Descriptions of forest stand conditions for specific sites on the Monterey Peninsula are provided in Appendix A.

Huffman and Associates (1994) rated stands of Monterey pine for overall stand health on a four-grade scale: good, fair, declining, and senescent. About 65% of the stands at Monterey were identified as in fair or good health. Of the stands that rated declining or senescent, only three stands totalling less than 100 acres were rated senescent. Half of the stands at Cambria, representing about 63% of the forest acreage, were rated declining or senescent because of the high incidence of coastal dwarf mistletoe, gall rusts, and bark beetles (Huffman and Associates 1994). The health of all stands in of the Año Nuevo forest was rated as fair or good by Huffman and Associates (1994).

GENETIC EFFECTS OF NURSERY STOCK

Non-local nursery stock of Monterey pine has been planted throughout the Monterey area, particularly along roads and at private residences and commercial developments. Most of these trees were likely derived from New Zealand from a source known as the "Nelson first thinnings" (Libby pers. comm.). These New Zealand pines are genetically similar to both Año Nuevo and Monterey populations (Libby pers. comm.). Problematic traits that these New Zealand trees exhibit include bigger branches and "forky" or crooked growth (Libby pers. comm.). Also planted in the Monterey area, but to a much lesser extent, are New Zealand trees that have been bred for good timber traits, such as faster growth, stem straightness, and increased number of branches of small size. Some Monterey pines from Cambria stock have been planted at Monterey, many by the California Department of Forestry and Fire Protection (Libby pers. comm.). All of these sources of non-local genes can result in genetic contamination of the local native Monterey pine forest.

Genetic studies indicate that gene flow may be widespread in Monterey pine populations (Libby pers. comm.). See the discussion of allozyme variation under "Systematics/Taxonomic Relationships". If this is the case, then genetic contamination from nursery stock could occur rapidly over large areas. Long-distance gene flow is most likely through windborne pollen grains.

The genetic risks to the Monterey population of pines are that:

- genes from the Año Nuevo population will infiltrate and dilute the genetic differences between these two populations;
- genes from the Cambria population will infiltrate and dilute the genetic differences between these two populations; and
- genes that code for traits selected in New Zealand commercial stock will increase in the Monterey population, resulting in trees less adapted to local natural conditions.

Initially, non-local genes can move into the native populations through cross-pollination from the non-local trees to local trees and seed dispersal from non-local trees into the native forest. Once established in the native forest, non-local genes become subject to the effects of natural selection and random genetic changes such as genetic drift. These genes may increase or decrease in frequency over time. Planted trees of non-local stock will continue to contaminate native forests with non-local genes as long as these trees survive near the native forests. The ratio of numbers of non-local to local native trees and the proximity of these trees to each other determines to what extent native forest will be inundated with non-local genes. About half of the native forest at Monterey is within 500 feet of known stands of non-local Monterey pine and is considered to be at high risk of genetic contamination (Huffman and Associates 1994). If gene flow distances are greater than the 500 feet estimated by Huffman and Associates (1994), then over half the forest at Monterey could be at risk.

If nursery stock are more susceptible to pitch canker than native stock, then genetic contamination is of more serious concern. Introduction of nursery stock genes could reduce the resistance to pitch canker of forest trees.

Only limited non-local pine plantings are present at Año Nuevo and Cambria and the native stands of Monterey pine are apparently not threatened by genetic contamination at this time (Huffman and Associates 1994).

LAND USE

Año Nuevo

The Año Nuevo forests were repeatedly burned in the early 1900s and these fires probably favored Monterey pine over Douglas fir (Scott 1960). Current land uses at Año Nuevo are 30 acres in public parks and 1,470 acres in private unprotected lumber company and ranch lands (Huffman and Associates 1994). Currently, no commercial lumbering of

Monterey pine occurs at Año Nuevo (Huffman and Associates 1994). Vogl et al. (1988) report that Monterey pine seedling establishment does not appear to be affected by grazing.

Monterey

The early Spanish colonists cut only small portions of the pine forest in the area immediately surrounding the town and mission of Monterey (Stoddard 1947). The Spanish may have used fire to convert pine forests to grazing land. Later the forest was cut to establish the towns of Pacific Grove, Carmel, and New Monterey (Stoddard 1947). Most of the Monterey pine forest on the 7000-acre Pacific Improvement Company property near Monterey and Pacific Grove was cut down in the 1860s and lumbered at the Sawmill Gulch sawmill near Seventeen Mile Drive (Coleman 1905). Coleman (1905) reports that in his surveys of 1904 and 1905 on the Pacific Improvement Company property "the majority of pines are not more than thirty-five to forty years of age, with occasionally a mature pine, some of which on cutting show annual rings to the number of one hundred or even a few more."

To relieve local lumber shortages, logging of Monterey pine was reinitiated in the in 1946 and supported a mill near Pacific Grove (Stoddard 1947). Most of the lumber was sold locally for home construction (Stoddard 1947). Logging continued in the 1950s for lumber and fuel wood, supporting the Carmel Lumber Company sawmill (McDonald 1959). Seed trees were left at many logging sites, varying from 15-40 per acre (McDonald 1959).

From the 1950s through the present, urban, suburban, and recreational development has reduced the extent and fragmented the forest at Monterey, especially on the Monterey Peninsula. Estimates by Huffman and Associates (1994) are that about 4,100-5,100 acres of forest have been replaced by urban, suburban, and recreational development. Huffman and Associates (1994) estimate that about 2,900 acres of remaining Monterey pine forest are in public parks or dedicated open space on private land and about 4,000 acres are on private, unprotected land.

At Monterey, Jones & Stokes Associates' data indicate that about 9,405 acres of Monterey pine forest remain in undeveloped areas with mostly natural understory vegetation (Figure 9). These sites include public and private lands and offer the best opportunity for forest conservation. Approximately 1,554 acres of Monterey pine forest, much of it with a closed canopy, occur in rural areas. Some native understory vegetation is still present in rural development areas. In many rural developments the understory has been cleared or is closely managed, however the soil may be intact and able to support natural vegetation.

Suburban neighborhoods support about 2,811 acres of Monterey pine canopy, usually at more than 20% cover. Suburban development areas support an understory of unnatural landscaping vegetation as well as a greater density of structures and paved surface than rural areas. Urban, golf course, and urban park areas support scattered Monterey pines, at some sites reaching 20% canopy cover, over an area of about 3,693 acres. Monterey pines in

these areas are mostly street and landscaping trees and no natural understory is present. The density of structures and paved surface is very high except in golf course turf areas. Heavily urban areas of Monterey, New Monterey, Pacific Grove, and Carmel support Monterey pine as widely scattered street trees over an area of approximately 2,112 acres. These areas support no natural vegetation and the density of structures and paved surface is very high.

Descriptions of land uses at specific sites on the Monterey Peninsula are given in Appendix A.

Cambria

Historically, repeated logging has occurred in parts of the Cambria forest and portions have been burned to improve forage for cattle (Roy 1966). Urban and suburban development, mostly in the town of Cambria, have removed about 1200 acres of natural forest (Huffman and Associates 1994). Currently, no commercial logging occurs in the forest (Huffman and Associates 1994).

Guadalupe

On Guadalupe Island, regeneration of Monterey pine has been nearly eliminated by grazing goats (Libby et al. 1968). By 1988, goat activity had nearly eliminated the Monterey pine forest on Guadalupe Island (Libby 1990).

Cedros

Goats are present on Cedros Island, but do not seem to be substantially adversely affecting Monterey pine regeneration (Libby et al. 1968).

COMPARISON OF ECOLOGICAL CONDITIONS AND LAND USE

Jones & Stokes Associates used GIS-based data to compare ecological conditions of Monterey pine forest with land use at Monterey. Undeveloped areas supporting Monterey pine forest are the most readily conserved and managed stands. Approximately 9,405 acres of Monterey pine forest occur in undeveloped areas. It is in these areas that ecological succession, natural selection, and natural disturbances can be allowed to occur and the widest variety of management tools can be used.

Approximately 51% of the historical extent of Monterey pine forest remains in undeveloped areas. However, the removal of Monterey pine forest on different geomorphic surfaces has not been evenly distributed (Table 2 and Figure 12). Monterey pine forest subtypes on marine terraces and stabilized dunes have sustained the largest losses relative to the historical extent of these subtypes (Table 2). Remaining undeveloped forest is 20% or less on marine terraces 2, 3, and 4 and middle-aged and oldest stabilized dunes (Table 2). Jones & Stokes Associates (1994a) identified the relationship between subtypes of Monterey pine forest, soils, and geomorphic surfaces. Each geomorphic surface supports different environmental conditions that impose different selective pressures on Monterey pine and its associated species. Conserving representative examples of Monterey pine forest with natural understory from each geomorphic surface is vital to the conservation of Monterey pine forest diversity and the ecological and genetic variation and health of Monterey pine as a species. Undeveloped areas of Monterey pine forest on marine terraces and stabilized dunes should be given highest priority in conservation planning (Figure 12). Even if these stands are small, they are all that remain of unique forest subtypes.

Stand conditions in the undeveloped Monterey pine forest are the result of past forest management practices. Each site has its own history of establishment, management, and neglect. As discussed under the section "Stand Health," much of the forest is aging and becoming highly susceptible to disease and catastrophic fire. Some specific examples of forest stand conditions and history are described in Appendix A.

Approximately 1,554 acres of Monterey pine forest at Monterey occur in areas of rural development (Figure 9). These forests may have a natural canopy, but the understory vegetation has often been removed or modified. Forests in rural areas offer an opportunity for conservation of Monterey pine genetic variability. The potential exists for the enhancement of understory vegetation in these forests if landowners can be educated and provided with incentives. Rural areas could be used to increase the extent of forest subtypes on marine terraces and dunes. In rural areas on marine terraces 2, 4, 5, and 6, approximately 79, 77, 102, 73, and 25 acres of forest occur, respectively. Approximately 22 acres of rural forest occur on middle-aged dunes and 26 acres on the oldest dunes. Over 1,000 acres of rurally developed Monterey pine forest occur on shale and granite bedrock formations, mostly in inland areas.

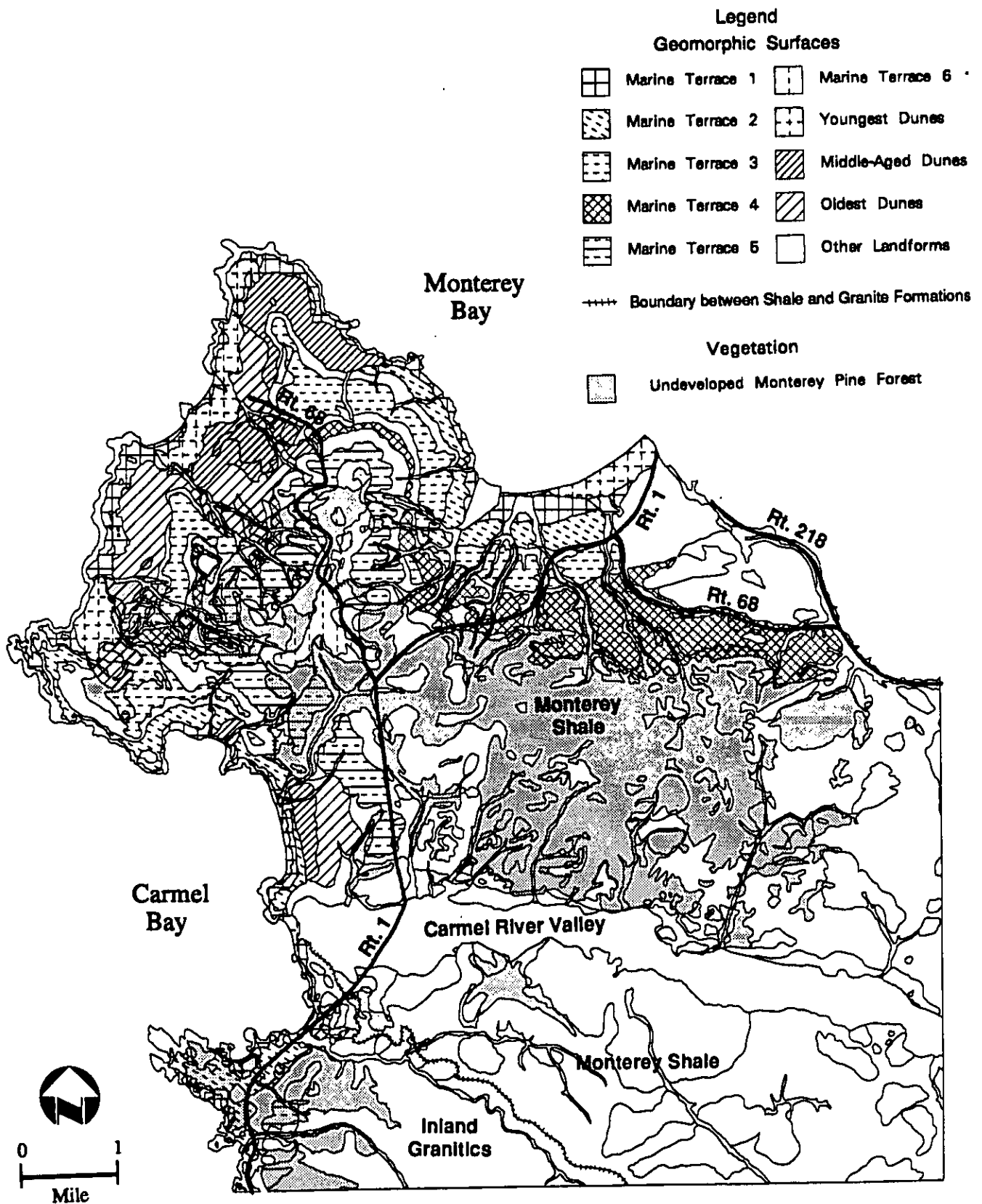
Approximately 2,811 acres of suburban developments on the Monterey Peninsula support Monterey pine cover of greater than 20%. Proper management of these stands could provide increased numbers of Monterey pine, contributing to the genetic health of the forest. Sparse occurrences of Monterey pine in urban areas and slightly higher densities in urban, golf course, and urban park areas may also be managed such that they contribute to the overall genetic health of Monterey pine.

Table 2. Estimate of Extent of Monterey Pine Forest
in Undeveloped Areas by Geomorphic Surface

Geomorphic Surface	Area (acres) ^a	Percentage of Historical Extent
Marine terrace 1	43	--
Marine terrace 2	170	16
Marine terrace 3	161	12
Marine terrace 4	318 ^b	20
Marine terrace 5	457	37
Marine terrace 6	82	31
Undetermined marine terraces	219	52
Youngest dunes	15	--
Middle-aged dunes	123	15
Oldest dunes	229	20
Inland shale	4,722	79
Inland granite	1,194	49
Other surfaces	1,430	92
Undetermined surfaces	<u>242</u>	<u>43</u>
Total extent of undeveloped forest	9,405	51

^a Estimates based on the overlap between areas mapped by Jones & Stokes Associates as undeveloped Monterey pine forest (forest with natural understory) and geomorphic surfaces as mapped by Dupré (1990).

^b Of this total, 80 acres are on granite-derived terraces and 238 on shale-derived terraces.



Jones & Stokes Associates, Inc.

Figure 12
Undeveloped Monterey Pine Forest by
Geomorphic Surface

CONCLUSIONS

A large body of published and unpublished information about Monterey pine is available (Jones & Stokes Associates 1994b). However, new discoveries are still being made concerning Monterey pine ecology and genetics. The information presented in this report will be used to develop a conservation plan for Monterey pine as a species and Monterey pine forest as a biological community. The five populations of Monterey pine are genetically distinct, but those distinctions are put at risk by transport and planting of locally non-native stock among native stands. The importance of Monterey pine to timber industries outside of the United States makes the indigenous populations of pine and the natural genetic variation they support all the more valuable.

The ongoing development pressure on pine forests at Monterey and the limited extent of publicly owned and protected pine forests at Cambria and Año Nuevo are conservation issues that will need to be addressed. The recent identification of soil-vegetation relationships and the variety of Monterey pine forest types at Monterey will be important in planning the conservation of Monterey pine forest such that the range of forest subtypes are conserved (Jones & Stokes Associates 1994a).

Pitch canker poses a new threat to Monterey pine. If effective control measures are not found, pitch canker could devastate planted trees. The effect that this fungus will have on natural forests of Monterey pine is uncertain. Given the overstocked, aged, and unhealthy conditions of most remaining stands of Monterey pine forest, the effects of pitch canker on natural forest could be devastating.

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Appendix A. Forest Stand Conditions and Land Uses at Selected Sites on the Monterey Peninsula

The following forest stand and land use information was gathered during a reconnaissance survey of the Monterey Peninsula conducted on February 16, 1994. Surveys were conducted by Nicholas Dennis, a registered professional forester with Jones & Stokes Associates, and Stephen Staub, an independent registered professional forester under contract to the Del Monte Forest Foundation. Site-specific information is presented as numbered field notes keyed to a street map of the Peninsula (Figure A-1).

1. Pebble Beach entrance gate kiosk. Twenty-year-old plantation, probably imported stock.
2. Twenty-year-old plantation. Pebble Beach Company land. Formerly used as wood-processing area.
3. Pebble Beach Company land planned for golf course residential development. Logged in 1950s; more recently treated to remove hazard trees. Damage from several diseases and insects displayed. Most trees have some defect, but on the whole, the stand is fairly healthy. Mixed ages present.

Typical stand development includes short crown (approximately 20% of stem length) indicative of crowded growing conditions.

Understory generally relatively open, although substantial oak component is present. Although 1-year-old seedlings are common, no saplings are present except in a few areas where sunlight is less limited.

Moderately heavy fuel loads (approximately 15 tons per acre), but low density of shrubs indicates absence of a fuel ladder and moderately low fire risk. Possible deer predation of seedlings.

Areas adjacent to proposed housing should have hazard trees removed and ground cleared of large debris and shrubs (especially needle-draped shrubs). Other areas probably do not need treatment at this time.

4. Mixed-age stand on steep land along Pescadero Canyon.
5. Area without trees. Uncertain why trees do not grow.

6. (Not assigned.)
7. (Not assigned.)
8. Largely even-aged, mature stand. Dense understory of coffeeberry and poison-oak probably discourages trespassing.
9. Eastern portion of McComber property. Mixed-age stands along Del Ciervo Road. Deficient in saplings. Probably has not been treated in 30 years.
10. Western portion of McComber property. Mixed-age stands with large component of mature trees. Substantial recent mortality has created openings. Stand is more advanced than polygon 9. Oak trees are common. Perimeter of property (totaling approximately 35 acres) is dedicated open space. Remainder will be developed for residences. Home sites have been thinned and ground has been cleared. Roadside redwood plantings; redwoods could be an alternative to Monterey pine if pitch canker turns out to be devastating. Fire in 1980s.
11. Private parcel (i.e., not owned by Pebble Beach Company). Advanced stand stage; snags and down trees common. Saplings, poles, and mature trees present. No management in recent decades.
12. Estate developments along creek. Approximately 50% pine canopy cover is typical, but some areas devoid of pines. Substantial broom invasion. Oaks in riparian corridor. Planted redwoods doing well. Uneven-aged tree groups among houses. City of Carmel behind ridge.
13. Small (4 acres) Del Monte Forest Foundation parcel. Dead trees have been removed from along road. Large oak component; more oak seedlings present than pine seedlings. Older stand will probably continue to suffer tree mortality, but overall fairly healthy. Poles and relatively young mature ("pointy-topped") trees are positioned to replace dying trees.
14. Rural-residential estates along Pebble Beach Golf Course.
15. Rural-residential with spectacular ocean view. Approximately 50% tree canopy; substantial oak component. Front-yard landscaping usually retains several large trees.
16. Rural-residential. Heavily landscaped. Fairly open canopy. Some brushfields. Relatively few pines.
17. Area without roads is too steep for development. Pine stands relatively young but mixed age.

LEGEND

24 Approximate location of site described in field notes with corresponding site number.

Note: Numbers 6 and 7 not used.

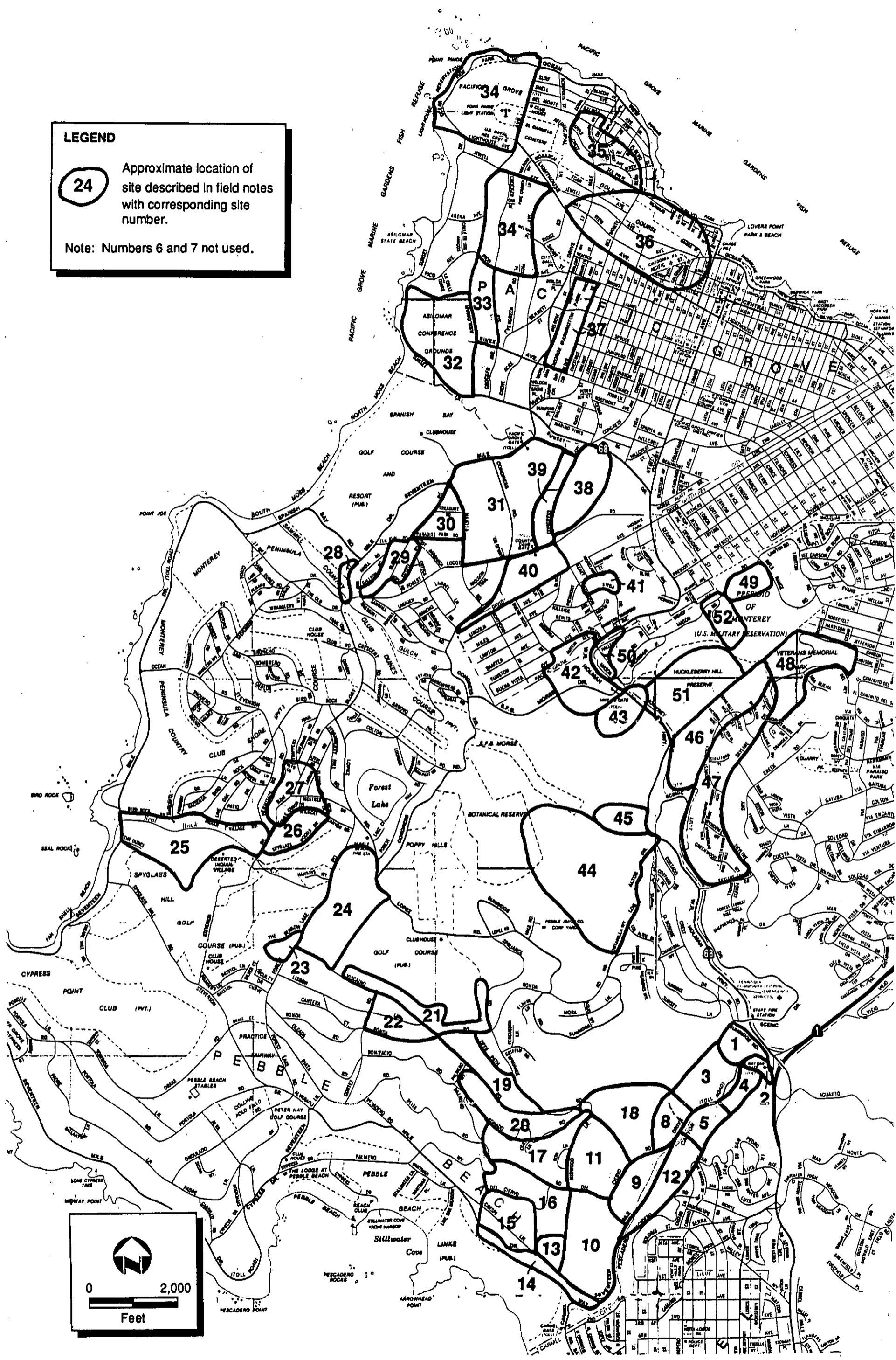


Figure A-1
Sites of Monterey Pine Forest Stands and Land Uses
Described in Field Notes

18. Pebble Beach Company land. Relatively even-aged stands. Old stumps indicate earlier thinnings. Fairly low site quality indicated by manzanita. Area near Viscaino Road has been logged and nearly cleared of pines.
19. Suburban. Many trees retained for landscaping, although tree presence varies by parcel. Some clumps of trees. Clean ground conditions. Many younger trees.
20. Steeper than polygon 19; some areas undevelopable. Mixed-age stands. Pines have been removed to benefit ocean views. Deer sighted.
21. Perimeter of Poppy Hills Golf Course. Strip habitat. Two-tiered pine stand. Thinned approximately 40 years ago.
22. Rural-residential estates recently constructed. Ground was cleared approximately 10 years ago; substantial debris has accumulated since. Many trees in strips (e.g., between Viscaino Road and Lisbon Lane). No ocean view, so trees have been retained.
23. Large open space. Old overstory. Clean ground conditions. Spy Glass Hill Golf Course to west.
24. Substantial open space. Mixed-age or two-tiered stands. Substantial oak component. Probably thinned at least 20 years ago. Variable understory. Low fuel loads. Low site quality.
25. Indian Village. Del Monte Forest Foundation land. Deeded open space. Mixed-age stands.
26. Suburban. Some areas dominated by clumps of very large trees; others completely landscaped. Canyons forested; uneven-aged stands. Clean ground conditions.
27. Suburban. Two-tiered canopy.
28. Strip of even-aged pine along beach and golf course. Suburban development on right.
29. Suburban. Even-aged stand on west side of Sloat; two-tiered stand on east.
30. Suburban with clumps of trees. Some fallen trees. Approximately 25% pine canopy; oaks becoming more dominant.
31. "Navajo Tract". Public foot access from Pacific Grove. Some cutting history but no recent management. Mixed-age stand.

32. Asilomar. According to Stone and McBride, wind damage increased after building sites were cleared; enlarged clearings were result. Sparse tree canopy (approximately 25%). Clean ground conditions, except many planted pine seedlings.
33. Suburban. Approximately 50% canopy on average but patchy. Some closed canopy.
34. Scrubby trees along beach, mostly Monterey cypress. Pine and cypress tree screens between fairways at Pacific Grove Golf Course.
35. Urban. Large cypress component; few pines among street trees. More pines toward inland.
36. Urban. Only a few trees; largest are eucalyptus.
37. George Washington Park. Key monarch butterfly wintering area. Conversion from pine to oak occurring. Understory depletion by foot traffic (not unexpected in a city park) may affect butterfly. Sparse old pine trees. Many planted pines along street unlikely to survive because of limited sunlight.
38. Stadium and school. A few trees.
39. Rip Van Winkle Park. Large oak component.
40. Large trees on undevelopable land and on Presidio form a backdrop to David Avenue.
41. Mixed-age forest open space. Heavy oak understory. Sparse pine overstory. Pebble Beach Company land to west.
42. Pebble Beach Company land at edge of Huckleberry Hill preserve. Decadent even-aged forest.
43. 1990 fire area. Prolific pine regeneration (at least 10,000 stems per acre). Most dead trees were felled; some were removed for firewood or burning at Soledad biomass energy plant. Burn crossed road onto Presidio.
44. 1987 Huckleberry Hill fire area.
45. Bishop pine stand.
46. Undevelopable steep area. Mixture of Monterey and Bishop pines. Some houses under trees.
47. Skyline Forest. Suburban. Trees with houses beneath. Houses heavily screened by trees. Mixture of even-aged and two-tiered stands. Fire clearance work has been

done recently. Some manual pruning of lower limbs. Strips of dense forest between housing. Some tree topping has occurred.

48. Veterans Memorial Park. Mostly forested; in good condition. Approximately 40% tree canopy. Large seedlings present (unusual). Clean ground conditions. Public campground. Substantial oak component. Large strip of forest occurs in canyon at west end of Jefferson Street.
49. Presidio of Monterey. Received heavy thinning. Moderately sparse stand of old trees.
50. Eucalyptus screen.
51. Large open space. Not recently managed; heavily forested. Evidence of old thinning. Heavy brush and broom understory.
52. Sports field.

**Selected Bibliography on
Monterey Pine
(*Pinus radiata* D. Don)**

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September 12, 1994

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Selected Bibliography on Monterey Pine (*Pinus radiata* D. Don)

A bibliography of published and unpublished reports that deal with Monterey pine (*Pinus radiata* D. Don) was compiled by Jones & Stokes Associates. The bibliography is annotated by topic area and focuses on topics that are relevant to the ecology and management of native Monterey pine stands in California.

A variety of sources were consulted to locate historic and recent published and unpublished reports, including University of California libraries (Berkeley, Davis, and Santa Cruz); California State University, Sacramento, library; California State Library; Pebble Beach Company; and DIALOG database. To the extent possible, Jones & Stokes Associates obtained and reviewed reports that related to ecology and management of Monterey pine stands. Jones & Stokes Associates is continuing to obtain published and unpublished reports. For this reason, the bibliography may be modified for the final report on Monterey pine forest ecology after additional publications are reviewed. Publications that provide the best overview of the ecology of Monterey pine include J.B. McDonald (1959), C. W. Scott (1960), D.F. Roy (1966), McDonald and Laacke (1990), and Huffman and Associates (1994).

A limited number of reports dealing with commercial distribution, forest products, silviculture, and distribution of planted stands outside of California are included in the annotated bibliography. The volume of material on these topics is quite large and these reports were, for the most part, not included in this annotated bibliography. For a more extensive listing of published reports that deal with these topic areas, refer to B. Marris (1965, 1966) and M. Pert (1961).

Fifteen broad topic areas were chosen to categorize Monterey pine reports. Each topic area was numbered to annotate publications in the bibliography. Topic areas that were developed after a review of selected reports are:

1. **Historical Distribution and General Historical Information:** Reports that describe historical accounts and theories on the distribution of Monterey pine.
2. **Present Distribution:** Reports that provide descriptive information and maps that depict the present distribution of Monterey pine in California.
3. **Evolution and Paleobotany:** Reports that discuss the evolution of the California closed-pine forest, origin of the Monterey endemic area, Pleistocene closed-pine flora, and fossil records.

4. **Reproduction and Regeneration:** Reports on factors that affect reproduction and regeneration of Monterey pine stands; information on pollination, seed dissemination, and pollen dispersal.
5. **Genetics:** Reports that present genetic studies, including population genetics, molecular genetics, and natural selection.
6. **Effects of Fire:** Reports that discuss the effects and role of fire in Monterey pine forest, including experimental prescribed burns in Monterey pine stands.
7. **Autecology/Environmental Factors:** Reports that cover Monterey pine's ecological relationship with soils, climate, and topography; including physiological and anatomical investigations.
8. **Variation and Taxonomic Relationships:** Reports that discuss variation in natural stands of Monterey pine and relationships with other closed-cone pines.
9. **Species Associations and Plant Succession:** Reports that discuss plants associated with Monterey pine stands and successional theories.
10. **Morphology:** Reports that discuss morphological variations in Monterey pines; this category is related to genetics and taxonomic relationships.
11. **Diseases and Disease Control:** Reports that include information on the identification and management of diseases that affect native and introduced Monterey pine stands.
12. **Conservation and Management:** Reports on conservation and management of Monterey pine stands in California.
13. **Commercial Distribution and Forest Products:** A limited number of reports provided in the bibliography deal with commercial distribution, forest products, and associated timber industry topics.
14. **Silviculture:** A limited number of reports provided in the bibliography deal with silvical characteristics of Monterey pine.
15. **General Information:** Reports that cover a broad range of subjects, including annotated bibliography lists.

An asterisk (*) placed before the following references indicates which report was obtained and reviewed by Jones & Stokes Associates. The remaining reports were not obtained by Jones & Stokes Associates and the annotation is based on the title or how the report was cited in another study. The summary bibliography is presented in alphabetical order, followed by list of reports under each topic area.

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